A Regional Simulation to Explore Impacts of Resource Use and Constraints

RSim

SI-1259

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14. ABSTRACT The Regional Simulator (RSim), designed to integrate land-use changes with ecological effects of changes in noise, water and air quality and species of special concern and their habitats. RSim projects land-use changes, its impacts for the five counties in Georgia surrounding and including Fort Benning, is applicable to other regions and a diversity of resource managers. Data layers that are widely available are being used in the model. Four scenarios implemented: urban growth, road-influenced urbanization, a new military training area, and hurricane impacts. Projections from the various scenarios suggest that urban growth will continue along the northern border of Fort Benning and may have impacts on noise, water, and air quality. Declines in habitat of gopher tortoise as a likely result of land-use changes because urban growth and other land-use changes are highly likely on lands that now provide this habitat. Habitat for red-cockaded woodpecker is not likely to be affected by projected land-cover changes under the urban growth and new military training scenarios because most of the limited habitat remaining for this species is under federal protection.			
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List of Acronyms

AQM	Air Quality Module
BAU	business as usual
CART	Classification and Regression Tree
CERL	Construction Engineering Research Laboratory
CHPPM	Center for Health Promotion and Preventive Medicine, U.S. Army
DoD	Department of Defense
DMPRC	Digital multipurpose range complex
EPA	Environmental Protection Agency
EPD	Environmental Protection Division
ERDC	Engineer Research and Development Center
FAQS	Fall line Air Quality Study
GA	Georgia
GCOS	Gulf Coast Ozone Study
GIS	geographical information systems
HUC	Hydrological Unit
INRMP	Integrated Natural Resources Management Plan
LCTA	Land Condition Trend Analysis
MRLC	Multi-Resolution Land Characteristics
N	Nitrogen
NAAQS	National Ambient Air Quality Standard
NLCD	National Land Cover Datasets
NOx	Nitrous oxides
O_3	ambient oxygen
ORNL	Oak Ridge National Laboratory
OTAG	Ozone Transport Assessment Group
P	phosphorus
R&D	Research and Development
RCW	Red-cockaded woodpecker
RSim	Regional Simulator
SAMI	Southern Appalachian Mountain Initiative
SEMP	SERDP Ecosystem Management Project
SERDP	Strategic Environmental Research and Development Program
TNC	The Nature Conservancy
USAIC	United States Army Infantry Center
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VOCs	Volatile organic compounds

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Executive Summary

The computer simulation model, the Regional Simulator (RSim), was constructed to project how land-use changes affect the quality of water, air, noise, and habitat of species of special concern. RSim is designed to simulate these environmental impacts for the five counties in Georgia surrounding and including Fort Benning. The model combines existing data and modeling approaches to simulate effects of land-cover changes on nutrient export by hydrologic unit; peak 8-hour average ozone concentrations; noise impacts due to small arms and blasts, and habitat changes for the rare red-cockaded woodpecker (*Picoides borealis*) and gopher tortoise (*Gopherus polyphemus*).

RSim integrates various stressors and receptors through the linkages depicted in Figure 1. Stressors can act directly on receptors (e.g., noise acting on gopher tortoise or ozone acting on pines), or stressors can act indirectly on receptors via their habitat (e.g., ozone acting on red-cockaded woodpecker by adversely affecting pines). Integration can occur at the level of exposure, for example, if there are multiple sources of nitrogen in streams or ozone in air or blast noise. Similarly, the road-based and non-road-based urbanization are integrated in RSim. Or integration can occur at the level of effects (e.g., changes in abundance resulting from multiple causes of habitat removal and fragmentation, or changes in abundance resulting from the multiple stressors of habitat change, noise, and air pollution).

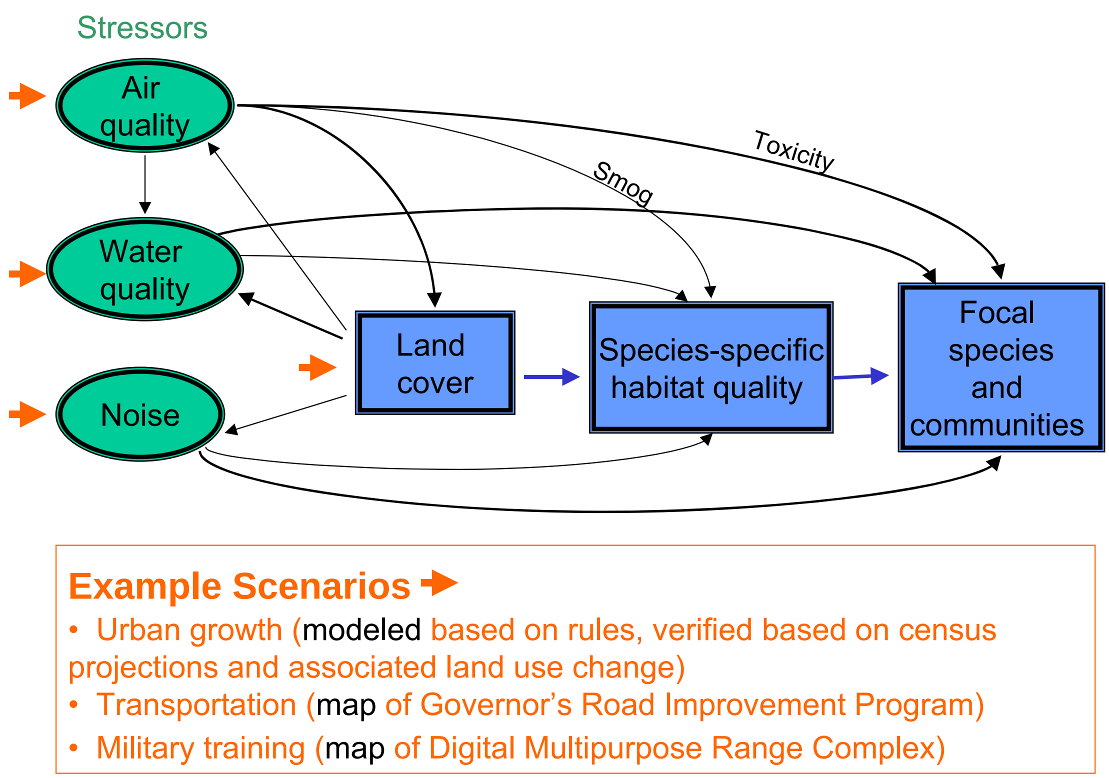

Figure 1. Integrated framework for RSim, showing example scenarios acting on stressors.

Four scenarios have been implemented in RSim. (A) The urban growth submodel in RSim consists of spontaneous growth of new urban areas and patch growth (growth of preexisting urban patches). (B) The road-influenced urbanization submodel focuses growth on areas near existing and new roads by considering the proximity of major roads to newly urbanized areas. (C) The new digital multipurpose range complex (DMPRC) at Fort Benning is an example of the pressures that are now being placed on military land for more use. (D) Spatially explicit impacts of a hurricane impact from a storm moving northward from the Gulf of Mexico are based on a storm that impacts the South Carolina coastal system.

For this report, the model was run under scenarios of business as usual (BAU) and greatly increased urban growth for the region. The projections show that high urban growth will likely impact nitrogen and phosphorus loadings to surface water as well as noise, but not ozone levels in air (at least in the absence of associated increases in industry and transportation use or technology changes). Effects of urban growth on existing populations of the federally endangered red-cockaded woodpecker are not anticipated. Habitat for red-cockaded woodpecker are not likely to be affected by projected land-cover changes under scenarios A, B and C for two reasons: (1) only 3% of the original habitat remains and (2) most of those remaining sites are on federally protected land that is managed for red-cockaded woodpecker. In contrast, under the simulation conditions, habitat for gopher tortoise in the five-county region declines by 5% and 40% in the BAU and high urban growth scenarios, respectively. RSim is designed to assess environmental impacts of planning activities both inside and outside the installation and to address concerns related to encroachment and transboundary influences.

RSim has been placed within the context of the region, ongoing military issues, and current theory. We specifically considered RSim in relation to future plans for the five-county region, transboundary issues at military installations, and the ecological theories relating to environmental security, ecological risk, and land use planning. We also developed a user-friendly interface for RSim so that the transfer of the final product will go smoothly and provide a worthwhile technology. This task involved planning by our computer design team and discussions with personal at Fort Benning and The Nature Conservancy. We published aspects of the work as it is completed, for submitting the work to peer review is the established method to gain scientific credibility necessary to have confidence that the methods are appropriate for resource management

1. Objective

A regional approach to environmental impacts (Munns 2006) provides the opportunity to examine the extent and spatial interactions of key drivers and processes affected by land-use change. Because these drivers and the factors influencing these processes change over space due to variations in such features as topography, climate, and human activities, it is important to consider their influence in a spatial context in order to understand the full range and extent of causes and implications of environmental change. Such analyses can be of assistance to regional planning and hence foster sustainability by allowing potential environmental repercussions to be a part of planning.

Furthermore, there is a need to examine how environmental impacts can change across several stressors, environmental media, and sectors (e.g., water, air, noise, and habitats for species of special concern). Although environmental laws typically segregate these impacts both in the ways they are reported and managed, such an artificial division can lead to inadequate understanding and, hence, management problems. For example, contrary incentives can arise if one sector gains at the expense of another. In other situations, inappropriate management actions can result from the focus on only one sector and not the consideration of all aspects of the environment that might be affected.

As a major driver of environmental change, it is critical to understand how land-use activities affect the landscape. For example, human use can degrade or ameliorate soil properties, enhance or reduce runoff, and aggravate or alleviate drought. In turn, land use can be constrained by environmental conditions such as topography, slope, exposure, soil conditions, and climate.

With the recent advent of geographic information systems and the field of landscape ecology (Turner et al. 2001), it has been possible for such a spatial approach to environmental change to be conducted. Undertaking a regional and cross-sectorial approach to the study of environmental change requires determination of the appropriate spatial and temporal scales of resolution and consideration of potential feedbacks across sectors. One of the goals in such a multi-sector approach is to provide a way to fully understand the key components of the system including possible cumulative impacts.

This project developed a regional, cross-sectorial approach to examining land-use change and its effects and presents an example of its application to a five-county region in west, central Georgia. We focus on the region in Georgia around and inclusive of Fort Benning for three reasons: (1) large quantities of data are available; (2) the region will be undergoing dramatic changes in the future as the military training activities and the many people supporting them now at Fort Knox, Kentucky, are moved to Fort Benning; and (3) the military land (on which urban growth is restricted) serves as a control against which changes on private lands can be compared. The Regional Simulator model (RSim) has been developed for this five-county region and includes the ability to project future changes in the quality of water, air, noise, and habitat (Dale et al. 2005). The spatially-explicit simulation model is structured so that the basic framework can be applied to other resource management needs and other regions. Hence, the model is designed so that it is broadly applicable to environmental management concerns. The need for applying ecosystem management approaches to military lands and regions that contain them is critical because of unique resources on these public lands and the fact that conservation issues for the entire region may jeopardize military missions if not appropriately managed. The RSim model addresses this critical need by enabling application of ecosystem management approaches to military lands and surrounding regions. This report examines changes that result from two scenarios: a "business as usual" (BAU) case and a dramatic increase in urban growth. The analysis illustrates how a simulation model can be used as a cost-effective means to explore potential environmental ramifications of land-use changes.

This project focuses on forest sustainability because the study region was originally dominated by long-leaf pine (*Pinus palustris*) forest, and it is the continuance of the pine forest that allows many other environmental goals for the region to be attained. Without the forest, some of the other environmental amenities such as wildlife habitat are not possible. Environmental impacts of planning activities both inside and outside military installations need to address concerns related to encroachment and transboundary influences (Efroymson et al. 2005).

We developed a spatially-explicit simulation model that can enhance the abilities of military planners to understand the implications of external land-use change, resource use, and future development policy on the sustainability of military lands and missions. The model was designed to operate in a gaming mode to allow investigation into the impacts of alternative regional land-use futures on variables that potentially impact military.

2. Background

2.1 SERDP Relevance

As the Department of Defense's (DoD) Corporate Environmental R&D Program, the Strategic Environmental Research and Development Program (SERDP) is committed to focusing on conservation technologies that can assist DoD in meeting its mission needs. Because actions internal and external to a DoD installation can jeopardize mission activities, it is necessary to consider potential actions in a regional context. This proposed effort was designed to develop a user-friendly regional simulation that projects and assesses implications for the environment with respect to mission activities both internal and external to the base. The simulation tool was designed for and implemented in the region around Fort Benning, Georgia, but its use is applicable to other regions and concerns of both DoD installations and The Nature Conservancy's regional planning efforts (Poiani et al. 2000). The **R**egional **Sim**ulation (RSim) tool was designed to support the guiding principles of the 1994 memorandum from the Office of the Deputy Secretary of Defense for Environmental Security. Below we underline the ten guiding principles and discuss how the proposed work contributes to meeting them.

(1) <u>Maintain and approve sustainability and native biodiversity of ecosystems:</u> RSim helps land managers identify sustainability and biodiversity issues of concern and aspects of ecosystems at risk under certain management practices.

1. <u>Maintain and approve sustainability and native biodiversity of ecosystems</u>\: The ecological indicators will help land managers identify the sustainability and biodiversity issues of concern.

(2) Administer in accordance with ecological units and time frames: RSim was designed to accommodate issues at their relevant scales. For example, several temporal and spatial scales are included in the model. Part of the research was to identify the appropriate scales for ecosystem management, and RSim serves as a means to convey the relevant scale of each issue to managers.

(3) Support sustainable human activities: RSim can simulate human activities both on and off the installations, and focus on activities that affect noise, air quality, water quality and threatened and endangered species and their habitats.

(4) Develop a vision of ecosystem health: RSim was designed to project conditions under various scenarios of land use, training and testing, and growth of urban communities. Contrasts between different projections will serve to identify elements of ecosystem health at risk under different management and use plans.

(5) Develop priorities and reconcile conflicts: RSim can help regional and installation managers identify training and development priorities with respect to conservation priorities.

(6) Develop coordinated approaches to working toward ecosystem health: RSim can provide a methodology for DoD managers and surrounding communities to visualize coordinated approaches toward attaining ecosystem health.

(7) Rely on the best science available: This research is be state-of-the-art and incorporates the most current scientific understanding. RSim is composed of modules so that as scientific understanding is advanced, the most recent analysis can be incorporated into the respective module without invalidating other modules.

5. Develop priorities and reconcile conflicts: RSim will identify indicators which will help the military planners sort through mission priorities in relation to conservation priorities. The clear identification of indicators will help in the resolution of conflicts.

6. Develop coordinated approaches to working toward ecosystem health: Again, the indicators will help quantify components of ecosystem health and, therefore provide a way for DoD managers and surrounding communities to coordinate approaches toward meeting those mission and conservation goals.

7. Rely on the best science available: This research will be a state-of-the-art effort to implement ecosystem management by identifying critical indicators and their thresholds.

SIDEBAR\: An example of an ecological indicator is the presence of blue green algae (Virginia, my Latin is rusty, but we have inconsistent usage of alga and algae in this paragraph; are both correct?), Oscillatoria rubescens, in lakes on the verge of extreme eutrophication. The role of this alga as an indicator was first identified in Lake Washington (Edmondson and Lehman 1981; Edmondson 1991). In the first half of the 20th century, metropolitan Seattle discharged treated sewage high in phosphorus content into Lake Washington. By 1955, effluent contributed more than 50% of the total phosphorus input to the lake. Increased nutrient levels altered lake productivity and resulted in massive blooms of blue-green alga that negatively affected fish populations and greatly reduced water clarity. Public attention was called to the presence of the algae?, and the resulting reversal of this process occurred when sewage was diverted from the lake to Puget Sound. The resulting drop in nutrient additions eliminated algal blooms and increased water clarity. Now, Oscillatoria rubescens is used as an indicator of impending eutrophication worldwide. It satisfies three elements of an ecological indicator in that it is easily *measured, it signifies an impending change in the ecosystem, and both the potential ecosystem change and the high level of the indicator can be averted by management action*

(8) Use benchmarks to monitor and evaluate: The indicators developed under the SERDP Ecosystem Management Project (SEMP) will provide necessary reference points for RSim. Their inclusion within RSim will provide a way to test these indicators within a management framework.

(9) Use adaptive management: Different concepts of adaptive management (Holling 1998, Walters 1997) were be employed to identify which aspects of ecological and human systems need to be tested within RSim in order to effectively implement ecosystem management.

(10) Implement through installation plans and programs: This project was be tightly coordinated with staff at Fort Benning. However, discussions with environmental managers from other installations (e.g., Fort Stewart) and presentations of preliminary results at DoD meetings helped ensure that our approach is applicable to other installations.

2.2 Technical Approach

The U.S. military and other agencies have supported development of numerous models to simulate ecosystem components related to physical terrain and erosion, wildlife habitat and populations, biodiversity, and vegetation dynamics (e.g., the Army Training and Testing Area Carrying Capacity (ATTACC) model and installation-specific population models of red-cockaded woodpecker). Providing these models in an accessible format is the task of the Land Management System (LMS) Initiative (Goran et al. 1999). Several alternative future initiatives are underway which map out potential futures for an area. However, a 1997 SERDP-sponsored workshop on management-scale ecosystem research identified the need for focusing on the health of an entire ecosystem (Botkin et al. 1997). A way to address this concern is via ecosystem management, which can be defined as "a collaborative process that strives to reconcile the promotion of economic opportunities and livable communities with the conservation of ecological integrity and biodiversity" (The Keystone Center 1996). The need for applying ecosystem management approaches to military lands and regions that contain them is critical because of unique resources on these lands and the fact that conservation issues may jeopardize military missions if not appropriately managed. The proposed RSim model will address this critical need by enabling application of ecosystem management approaches to military lands and surrounding regions. The model is not only a way to integrate existing information (expressed in the form of data and models) and produce environmental planning maps, but it is also a method which promotes collaborative planning (Committee of Scientists 1999, Wondolleck and Yaffee 2000). Using the model requires stakeholders to investigate and learn about possible constraints on actions, implications of space and time on environmental decision-making, and potential impacts resulting from that decision-making.

3. Materials and Methods

3.1 Study Area

The study area for model development and application is a five-county region in west, central Georgia (Figure 2). This region encompasses and includes most of the 73,503 ha Fort Benning military installation, which supports both a cantonment, where infrastructure is extensive and also undeveloped areas where training occurs and where forest structure supports several environmental amenities. Fort Benning military activities include training entry-level soldiers, training the Infantry, and conducting Airborne and Ranger candidates' training. In addition to the ranges for munitions training, the installation supports expansive pine forests, which receive low-intensity military use. Because these forests have been protected from urban development and because there has been a focused program of controlled burning since the 1960s, these lands now support mature stands of long leaf pine forests and several rare species of plants and animals.

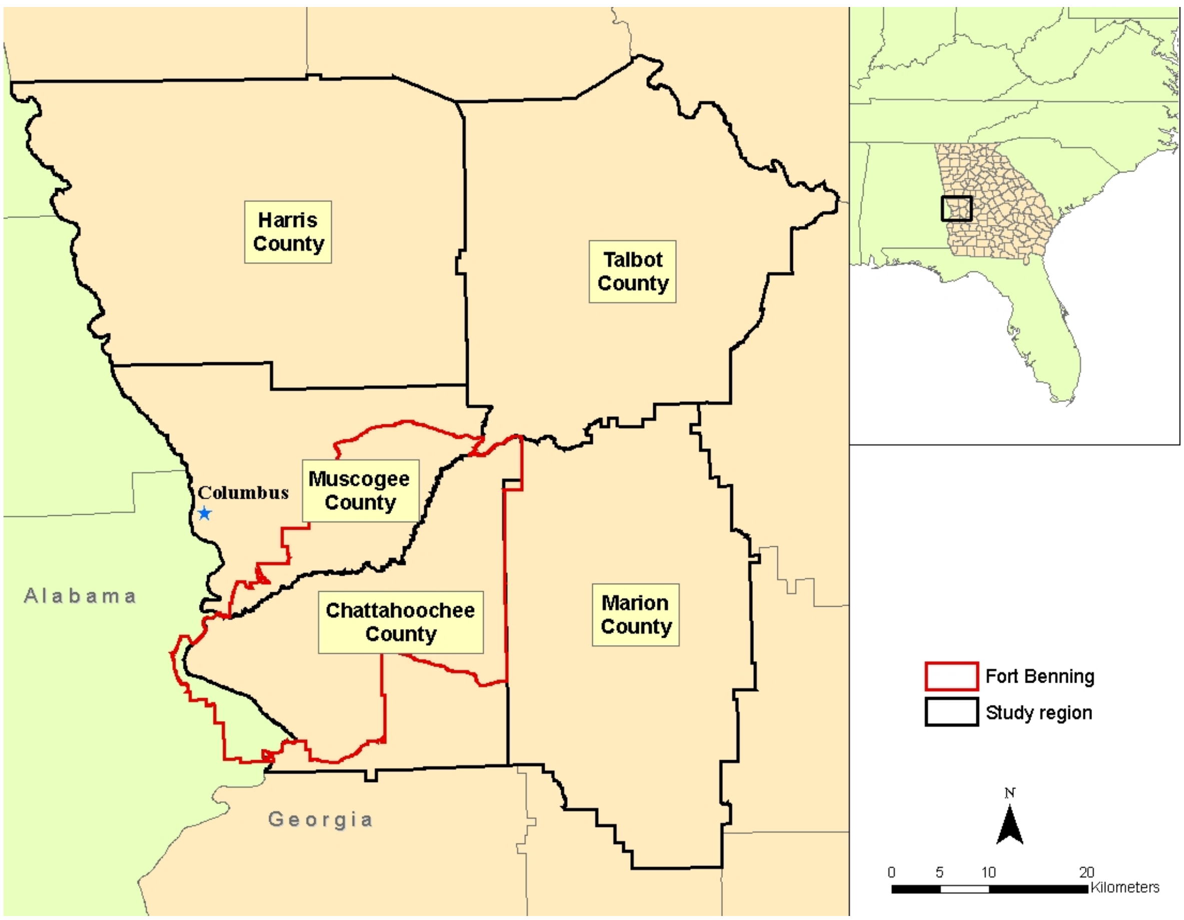

Figure 2. Map of the five-county region around Fort Benning to which RSim has been applied.

Because of land-use change and fire suppression throughout the southern eastern United States, only about 4% of the original long leaf pine forest exists today, and thus the remaining forest and the species that it supports has great ecological value (Gilliam and Platt 1999). Burning is a critical management practice for long leaf pine because the seedlings first grow in what is termed a "grass stage," in which the tree's meristem is located at the base of the stem and protected from low-intensity fire by a lush bunch of needles. A subsequent bolt of growth in saplings moves the meristem to a height above that of ground fires (assuming the fires occur frequently enough that they are of low intensity). In the 1994 Guidelines for the Management of Red-Cockaded Woodpeckers on Army Lands (as cited by Beaty et al. 2003), the Army in cooperation with the Fish and Wildlife Service selected Fort Benning as a site designated for the protection of the federally endangered red-cockaded woodpecker (*Picoides borealis*) which nests in living long leaf pine trees. Controlled burning not only allows for the reestablishment of long leaf pine seedlings, it also reduces hardwood ingrowth, which compromises the forest for support of red-cockaded woodpeckers.

The study region also includes private lands in the counties of Harris, Talbot, Muscogee, Chattahoochee, and Marion. The city of Columbus, which abuts Fort Benning on the north side, is the center of urban development in the region and is part of the study area. Major non-urban land uses of the five-county region include forestry, agriculture and pasture.

The region contains a complex mix of environmental pressures that can affect the quality of water, air, noise, and habitat. The urban areas have significant industrial development and intense use of fossil fuel-based vehicles, both of which contribute to air pollution. Burning for maintenance of habitat for long leaf pine also affects air quality and soil conditions (Garten 2006). Training areas within the installation produce loud noises as a result of small arms activity, firing of large caliber arms, and military aircraft. Water quality in the region is affected by industrial activities and agricultural practices, which induce runoff and require fertilizer use. In addition, habitat of two key rare species (red-cockaded woodpecker and gopher tortoise) can be affected by land-use practices and underlying conditions on the land (Bogliolo et al. 2000, Hermann et al. 2002).

3.2 Simulating Cross-Sectorial Environmental Changes in the Region

Because resource managers need to protect multiple aspects of the environmental quality of region, the Regional Simulator model (RSim) was developed as a tool to integrate changes in the region for conditions relating to water, air, noise, and habitat (Figure 1) (Dale et al. 2005). The basic spatial unit of RSim is a 30-m pixel because much of the underlying data in the model are derived from satellite imagery, which is reported at that scale of resolution. After much consideration, the basic time step of RSim was set to a year because changes in land cover typically are reported at annual intervals. This choice means that all the environmental changes projected by RSim are reported annually.

Where possible, RSim was built from existing models and data. Urban growth in RSim is based upon the SLEUTH model (Clarke et al. 1998, Clarke and Gaydos 1998, Candos 2002) supplemented with rules for low intensity to high intensity urbanization, and transitions for the non-urban land cover are based on change detection observed for the five-county region from 1990 to 1998 (Baskaran et al. 2006A). The water quality module uses nutrient export coefficients (e.g., Johnes, 1996; Mattikalli and Richards, 1996) combined with information on the different land uses and land covers in the region to predict the annual flux of N and P from terrestrial watersheds. The noise module uses GIS data layers of military noise exposure developed by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) as part of the Fort Benning Installation Environmental Noise Management Plan (IENMP). RSim builds upon noise guideline levels developed by the military under the Army's Environmental

Noise Program [ENP] (U.S. Army. Army Regulation 200-1. 1997) and contains noise contour maps developed from three Department of Defense noise simulation models: NOISEMAP (aircraft), BNOISE (artillery), and SARNAM (small arms) but focuses on noise created by artillery, which have the greatest effect at Fort Benning. The approach produces noise contours that identify areas where noise levels are compatible or incompatible with noise-sensitive land covers outside of Fort Benning. The Army's Environmental Noise Program's guidelines define zones of high noise and accident potential and recommend uses compatible in these zones. Local planning agencies are encouraged to adopt these guidelines. The Air Quality module of RSim estimates the impact of emissions changes on ozone air quality using sensitivity coefficients available from the Fall line Air Quality Study (FAQS) (http://cure.eas.gatech.edu/faqs/index.html). The module predicting habitat for red-cockaded woodpecker was developed based on spatial data of long leaf pine in the region. The module that predicts habitat for the gopher tortoise (*Gopherus polyphemus*) was developed based on analysis of locations of gopher tortoise burrows at Fort Benning and tested for the larger five-county region (Baskaran et al. 2006B).

Numerous future scenarios can be modeled using RSim. These include both civilian and military land-cover changes. The current implementation of RSim includes four specific types of scenarios, along with their impacts on environmental conditions over the next decades: (1) urbanization (conversion of non-urban land cover to low-intensity urban and conversion of low-intensity to high-intensity urban), (2) planned road expansion plus modeled urbanization, (3) a new training area at Fort Benning, and (4) hurricanes of various intensities. Low-intensity urban land cover includes single-family residential areas, schools, city parks, cemeteries, playing fields, and campus-like institutions. High-intensity urban land cover includes paved areas with buildings and little vegetation. When outside of urban areas, these high intensity urban low covers include power substations and grain storage buildings.

For the case considered in this study, RSim was run under conditions meant to simulate "business as usual" (BAU) urbanization for 40 years into the future from 1998, as compared to great increases in urban growth (see Appendix for input conditions). The BAU case includes typical urbanization for the region as based on regional growth patterns from 1990 to 1998, the new training area at Fort Benning (which is already under construction), and road expansion according to the Governor's plans for development of four-lane highways in the region. The high growth scenario is identical except for an increase in urban growth starting in 1998. This scenario is meant to simulate changes in urban growth of the region that may result from the transfer of training from Fort Knox, Kentucky, to Fort Benning. Although many changes in the region are anticipated (Dale et al. 2005), no one has yet published an analysis of how these changes might affect land cover and other environmental conditions. Such a study can be useful for planning in the region in such ways as to foster sustainability. This project builds from the pending development in the five-county region of west, central Georgia to explore how a regional simulation model can be used to improve understanding of cross-sectorial regional environmental changes before those changes occur on the ground.

3.3 Habitat Patches in RSim

Critical habitat patch size is an important concept in ecology and ecological risk assessment (Carlsen et al. 2004). Habitat patches below a certain size may not support individuals or populations of particular species. We have developed algorithms within RSim to identify boundaries of habitat patches. Essentially, patches of contiguous land with identical land-cover or habitat suitability designations are identified using a modification of the Hoshen-Kopelman algorithm (Berry et al. 1994; Constantin et al. 1997). This computationally intensive algorithm gives a unique label to each spatially discontinuous habitat patch. Alternative rules for defining adjacency, such as whether or not diagonally adjacent cells of the same land-cover designation are in the same patch or whether cells a certain distance apart should be considered to be within the same patch, may influence the outcome of patch-finding algorithms.

The first implementation of this patch-finding algorithm is to identify habitat patches that are of a threshold size below which mature gopher tortoises have been observed to abandon (less than 2 ha, McCoy & Mushinsky 1988), but are otherwise suitable for gopher tortoise, according to our habitat model.

3.4 Air Quality Emissions Algorthim of RSim

3.4.1 About the Air Quality Module

The Air Quality Module (AQM) estimates how demographic and economic growth, technology advances, activity change, and land cover transformations affect ground-level ozone concentrations in the Columbus – Fort Benning, GA area. The AQM was developed at Georgia Techology Institute (Georgia Tech) and is largely based on air quality computer modeling completed during the Fall Line Air Quality Study (1999-2004) (Chang et al. 2004). Unlike the FAQS models though, the design of the AQM removes the computational load of traditional air quality modeling while remaining flexible enough for the user to test various future scenarios.

3.4.2 Air Quality In and Around the Columbus and Fort Benning, Georgia Area

Fort Benning is located in parts of Muscogee and Chattahoochee counties in the Columbus, Georgia metropolitan area. Presently, there are local concerns about excessively high ozone and fine particulate matter pollutant concentrations that could affect human and ecosystem health, regulatory compliance, and economic development. Though other pollutants are monitored in the region (e.g. sulfur dioxide, lead, and coarse particulate matter), there is no concern at this time that the concentrations of these pollutants are sufficiently high enough to be having any significant health or regulatory impacts. Thus, the focus of this analysis is on ozone and fine particulate matter.

<u>3.4.2.1 Ozone</u>

Ozone is not directly emitted into the atmosphere from any known source in any significant quantities. It is formed in the atmosphere from other chemical precursors that are emitted into the atmosphere from both human and natural sources. Sunlight provides the energy that drives the atmospheric photochemical reactions, and production peaks in the summer

Figure 3 Air quality monitoring in the Columbus / Fort Benning region of Georgia.

months when the sun's rays are most intense. The Georgia Environmental Protection Division (EPD) has operated two ambient ozone monitors in Muscogee County and near Fort Benning since the early 1980s. Data from the Crime Lab station northwest of Columbus and near the northernmost boundary of Fort Benning (see Figure 3) is available for all years between 1981 and the present and for the months April through October. Data from the Airport station is available for all years between 1983 and the present and the months April through October.

The National Ambient Air Quality Standard (NAAQS) for ozone is 0.085 ppmv averaged over 8 hours. Between 1981 and 2002, the Crime Lab station experienced an average of 2.9 days per year on which the NAAQS was exceeded. The worst year for ozone air quality at this station was 13 exceedance days in 1999. In contrast there have been many years when no violations of the 8-hour ozone NAAQS were recorded (1982, 1985, 1989, 1991, 1993, and 2001). The all-time highest 8-hour average ozone concentration recorded at this site is 0.105 ppmv recorded on 18 July 2000. As Figure 4 shows, there is a slight seasonal increase in ozone concentrations during the summer months. The average summer daily peak 8-hour average ozone concentration (June, July, August) is 0.050 ppmv.

Between 1983 and 2002, the Airport station experienced an average of 3.4 days per year on which the NAAQS was exceeded. The worst years for ozone air quality at this station were 1986, 1998, and 1999 when ozone concentrations exceeded the standard on 9 days of each year. Like the Crime Lab station however, there were also several years when no violations of the air quality standard were recorded (1985, 1989, 1992, 1993, and 2001). The all-time highest 8-hour average at this site is 0.117 ppmv recorded on 11 July 1983. Like the Crime Lab station, Figure 5 shows a slight seasonal increase in ozone concentrations during the summer months at the Columbus Airport station. The average summer daily peak 8-hour average ozone concentration (June, July, August) is 0.050 ppmv.

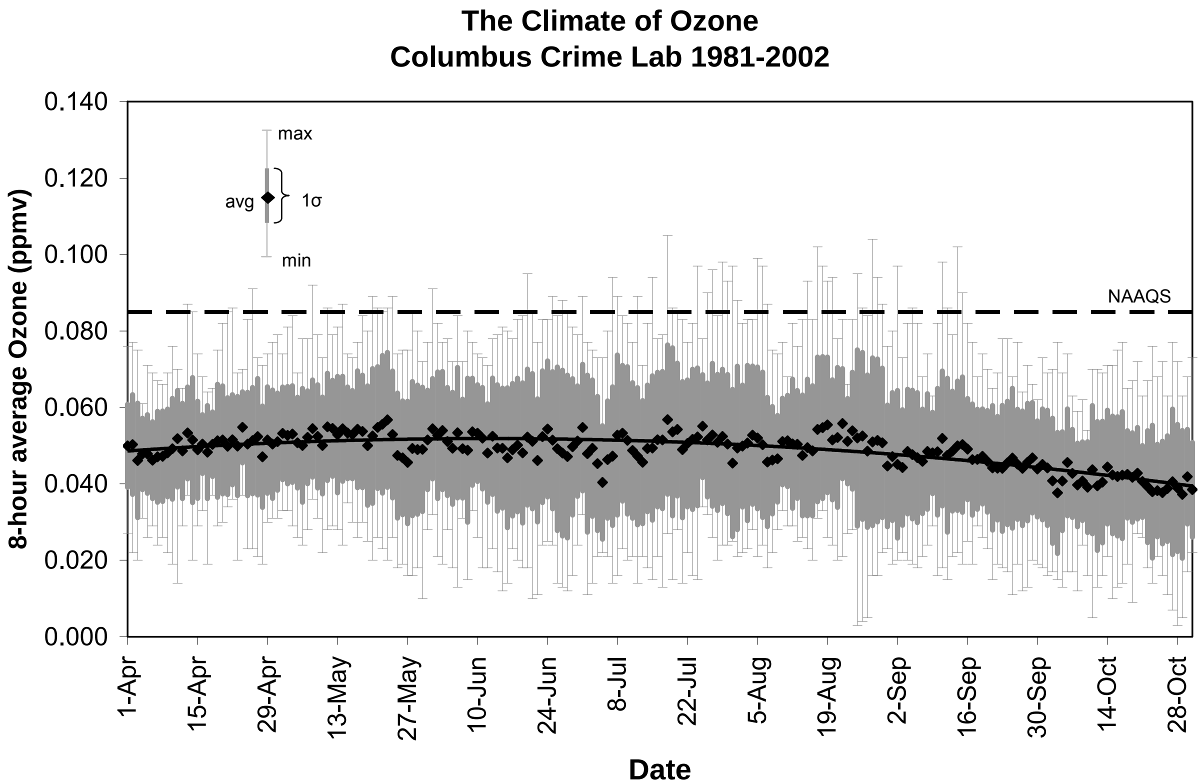

Figure 4 Long-term ozone season trends at Columbus Crime Lab station (data, GA EPD).

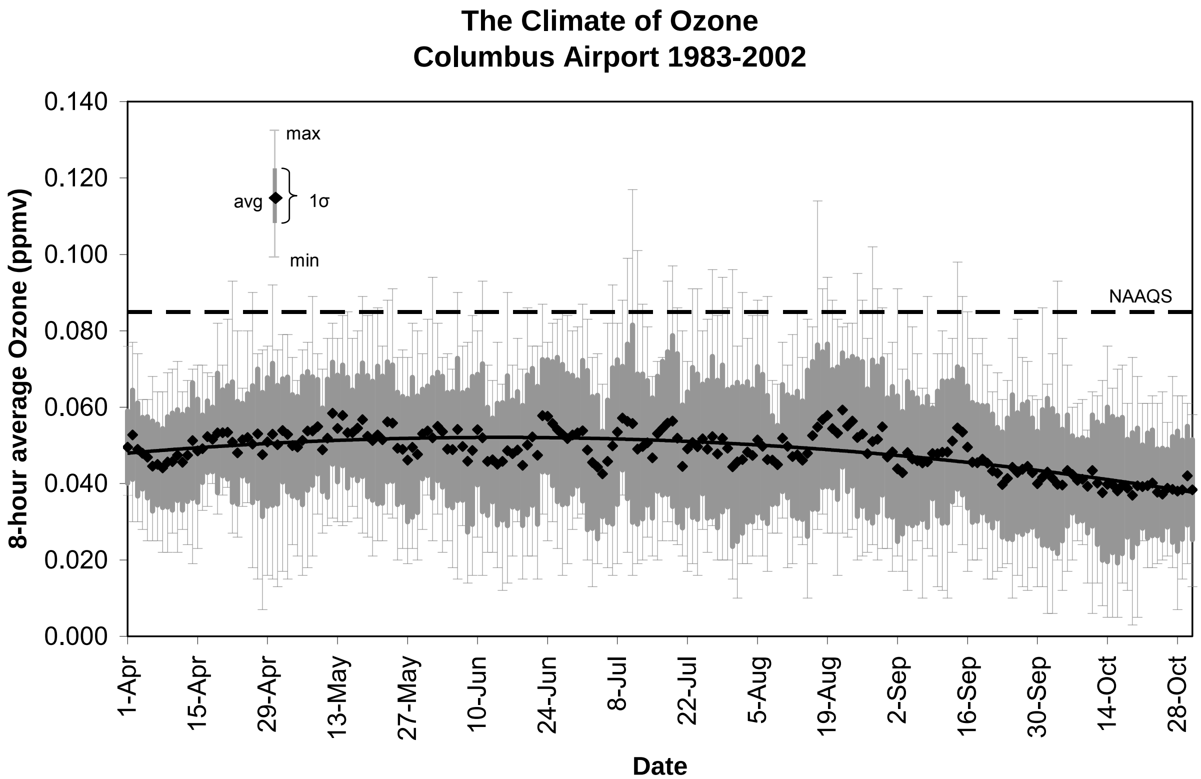

Figure 5. Long-term ozone season trends at Columbus Airport station (data, GA EPD).

A third ozone air quality monitor in the region was established in 2000 in the far southwestern corner of Muscogee County at the Oxbow Meadows Environmental Learning Center (see Figure 3). This monitor, discontinued in 2004, was part of the Fall line Air Quality Study (FAQS) being conducted by Georgia Tech on behalf of the State of Georgia (Chang et al. 2004). While there were some slight variations with the two long running GA EPD monitors, concentrations and trends were generally the same as the other two sites over the course of operations.

The US EPA designated areas as attainment or nonattainment of the 8-hour ozone NAAQS in April 2004. At that time and using data from 2001-2003, the design value[a] for the Columbus Crime Lab monitoring station was 0.073 ppmv and the design value for the Columbus Airport monitoring station was 0.074 ppmv. As a result of those design values at that time, the Columbus area was designated attainment for the 8-hour ozone NAAQS. Most recently, there were no exceedances of the ozone NAAQS at either the Crime Lab or Airport monitoring stations in 2003, 2004, or 2005. There were, however, three exceedances of the ozone NAAQS in 2006, all at the Airport station. Regarding design values, the Airport station reached a peak of 0.093 ppmv for the period 1998-2000 and during the same time period, the Crime Lab station also reached a peak design value of 0.089 ppmv. See Figure 6.

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[a] The design value is the 3-year average of the annual 4th highest 8-hour average ozone concentrations. If this value is greater than or equal to 0.085 ppmv, the area would meet the requirements for US EPA to designate it a "nonattainment" area for ozone, subject to the rules and regulations of the Clean Air Act.

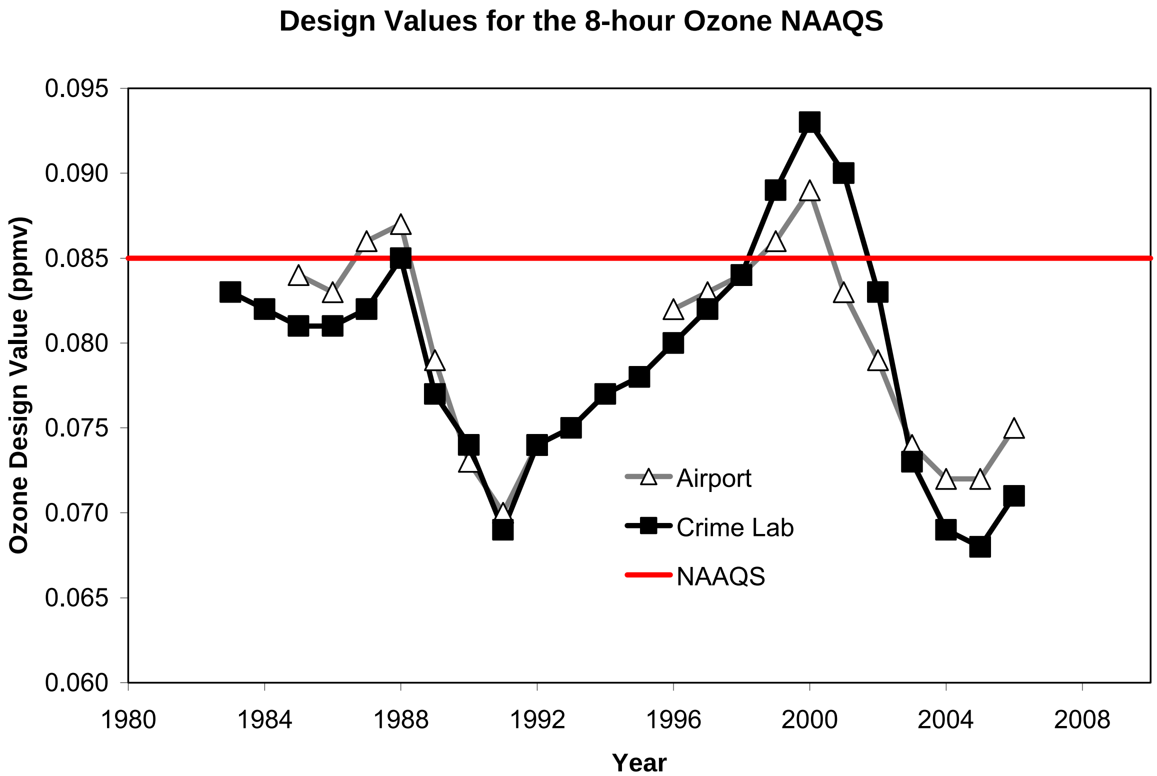


Figure 6. Four 8-hour ozone design values in the Columbus, GA area, 1983-2006.

3.4.2.2 Fine Particulate Matter

Fine particulate matter consists of liquid and solid aerosols having diameters of 2.5 microns or less. It is both emitted directly into the atmosphere as a primary pollutant, and forms in the atmosphere as a secondary pollutant resulting from physical and chemical combinations in the atmosphere. The GA EPD began monitoring fine particulate matter ($PM_{2.5}$) in 1999 at two stations: Cusseta Road School and the County Health Department. See Figure 3. Samples at these two stations are collected every 3 days. The NAAQS for $PM_{2.5}$ is 15 µg/m^3 for an annual average and 65 µg/m^3 for a daily, 24-hour average[b]. The annual average, peak daily maximum, and 98th percentile concentrations are shown for each year 1999 through 2005 in Table 1 Generally, higher concentrations of $PM_{2.5}$ were observed early in the period with lower concentrations following later.

The US EPA designated areas as attainment or nonattainment for the $PM_{2.5}$ NAAQS in December 2005. Using data from 2002-2004, the Columbus area was designated as being in attainment at that time. In September 2006, the US EPA proposed lowering the $PM_{2.5}$ daily NAAQS from 65 µg/m^3 to 35 µg/m^3.

[b] The annual standard is met when the three year average of the annual average PM2.5 concentration is less than 15 µg/m^3. The daily standard is met when the three year average of the 98th percentile PM2.5 concentration is less than 65 µg/m^3.

Table 1. PM2.5 trends in the Columbus / Fort Benning, Georgia region (US EPA).

	County Health Department				*Cussetta Road School*			
	Annual avg	3-yr avg Annual	98% Daily	3yr avg Daily	Annual avg	3-yr avg Annual	98% Daily	3yr avg Daily
1999	18.3		36.9		19.0		41.7	
2000	16.7		31.4		19.3		51.4	
2001	15.4	16.8	34.3	34.2	15.9	18.0	46.4	46.5
2002	14.2	15.4	30.8	32.2	13.8	16.3	31.2	43.0
2003	14.5	14.7	32.4	32.5	13.1	14.3	28.8	35.5
2004	14.7	14.5	37.4	33.5	15.1	14.0	41.4	33.8
2005	15.1	14.8	29.1	33.0	13.6	13.9	29.6	33.3

Continuous (as opposed to every 3 days by the GA EPD monitors) $PM_{2.5}$ measurements conducted during the FAQS in 2001 captured an exceptional event associated with a wildfire at Fort Benning. Figure 7 shows short-term $PM_{2.5}$ concentrations in the hazardous range during a three week span in October and November of 2001. Events such as these require further analysis, but suggest that wildfires and perhaps even prescribed burning activities at or near Fort Benning could have a significant short-term impact on local air quality.

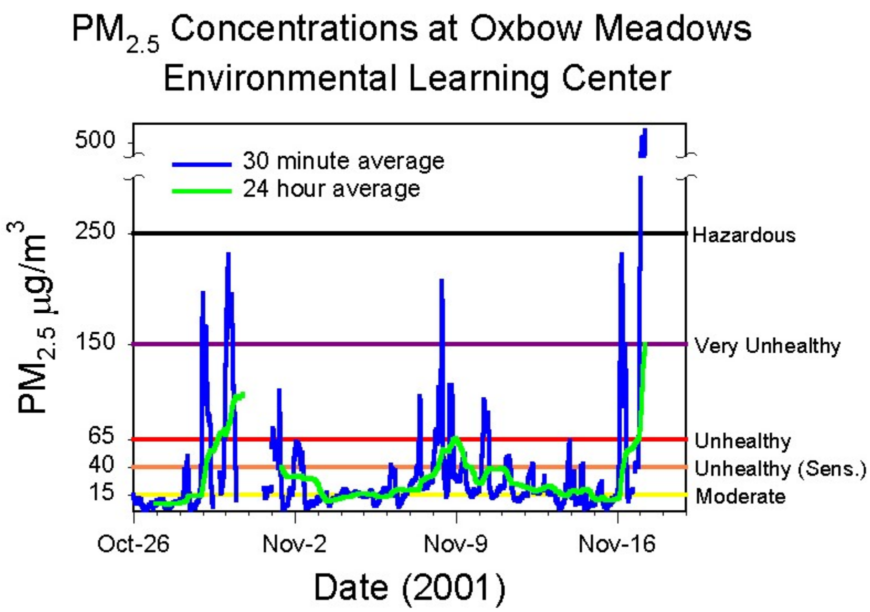


Figure 7. $PM_{2.5}$ concentrations at the Oxbow Meadows Environmental Learning Center during a series of wildfire events at Fort Benning.

3.4.3 Scope of the RSim Air Quality Module

As of October 2006, the Columbus – Fort Benning area is in attainment of all applicable air quality standards. Based on observed pollutant concentrations from the last decade (1996-2005), however, the area has on occasion seen both ozone and fine particulate concentrations that exceed federal air quality standards. Based on this history, it is reasonable to be wary of recurrent risks from both of these pollutants in the future. From its conception though, the RSim was intended to include only the means to assess impacts on future ozone air quality. Thus, RSim at this time, includes only future year impacts on ozone – estimated as the design value and relative to two selected meteorological events from 1999.

As noted previously, ozone concentrations reached historical maxima in the latter half of the 1990s, with 1999 being one of the worst years for the number of days exceeding the 8-hour ozone NAAQS. Meteorology in the southeastern U. S. in the late 1990s can generally be characterized as hot, dry, and stagnant relative to other years – conditions that are conducive to poor ozone air quality. As a historically "worst year," it is practical to assume that 1999 defines the upper limit of expectation for poor air quality, and that if one can "design" a management strategy that succeeds under this worst scenario, one can define a strategy that will be sufficiently effective for all scenarios past, present, and future. Ozone design values in the Columbus area in 1999 (using data from 1997 to 1999) ranged from 0.086 ppmv at the Airport monitoring station, to 0.089 ppmv at the Crime Lab monitoring station. Meteorological episodes for this RSim application were chosen that resulted in ozone concentrations that are near these ozone design values. On 4 August 1999, the Columbus area experienced an ozone event in which the peak 8-hour average ozone concentration was 0.083 ppmv. Several days later on 7 August 1999, the peak observed 8-hour average ozone concentration was 0.089 ppmv. In RSim then, the user can select between a mild ozone event, 4 August 1999, or a more extreme ozone event, 7 August 1999, to simulate air quality outcomes. Under either scenario and as the simulation progresses, the challenge for the user will be to find a means to manage air quality in order to keep the area in attainment or bring it back into attainment under these difficult meteorological conditions.

3.4.4 The Air Quality Module Algorithm

Air quality (χ) is a function of emissions (**E**), and meteorology (**M**), with χ, **E**, and **M** denoting vector quantities distributed in time and space:

$$\chi = fxn(\mathbf{E}, \mathbf{M})$$

Here meteorology is a constant. That is in RSim, the user selects from two historical ozone pollution episodes: a mild ozone day or a more extreme ozone day as described above. Simulations of future years use the selected meteorology, and any change in air quality relative to the base year is due only to a change in emissions:

$$\Delta\chi = fxn(\Delta\mathbf{E})$$

or

$$\chi_{\text{future}} = \chi_{\text{base}} + fxn(\Delta\mathbf{E})$$

The change in emissions is simply the growth in emissions from the base year (in the case of the air quality module, the base year is 1999):

$$\Delta\mathbf{E} = \mathbf{E}^{T}\mathbf{G}$$

Where

G is a vector of growth factors for each source type by location and future year (e.g. G may specify that mobile source emissions in Muscogee County may be expected to increase by

20% in the year 2030 relative to mobile source emissions in Muscogee County in the year 1999, and in the same location for the same period, industrial sources may only be expected to grow by 13%. As per the conventions of matrix algebra, $\mathbf{E}^T$ is the transpose of **E** for the base year.

Finally, the *fxn*(Δ**E**) is defined as:

$$\Delta\chi = fxn(\Delta\mathbf{E}) = \Delta\mathbf{E}^T\mathbf{P}$$

Where

P is a matrix of sensitivity coefficients making up the Area of Influence that relates changes in emissions (Δ**E**) to changes in air quality (Δχ) and are provided by the full air quality model runs of the Fall line Air Quality Study (that is changes in air quality from the base case were calculated for every small change in emissions from each source using the fully functional four-dimensional photochemical transport grid model developed for the FAQS and external to RSim).

Thus, the final form of the Air Quality Module is:

$$\chi_{\text{future}} = \chi_{\text{base}} + \mathbf{E}^T_{\text{base}}\mathbf{G}_{\text{future}}\mathbf{P}$$

3.4.4.1 Base Air Quality (χ_{base})

Ambient ozone (O_3) is a product of a series of chemical reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NOx). These reactions are directly activated by the sun's rays, and the more intense the sun, the more active are the chemical reactions. Somewhat indirectly, the sun also works to accelerate the chemical reactions as many of them are heat sensitive – the hotter it becomes, the faster are the reactions. The warmth of the sun also increases the rate of emissions of ozone precursors into the atmosphere, both VOCs and NOx. Thus, ozone formation is more favored on hot, sunny days than it is on cool, cloudy days.

$$\text{NOx} + \text{VOCs} + \text{sunlight} \rightarrow O_3$$

Once ozone is formed, advection and ventilation rates determine whether the pollutant readily disperses or slowly accumulates. On windy days or days when the atmosphere is vertically well mixed, ozone concentrations as measured at ground-level tend to be lower relative to other days when the air is stagnant. In summary, ozone concentrations largely depend on day-to-day meteorology. The goal of the RSim AQM, however, is to allow the user to explore how change in land-cover and land-use will affect air quality over the long-term without the confounding interference of short-term variants like meteorology. For this reason, users select a baseline meteorological episode which is then kept constant throughout the simulation period.

Using a Classification and Regression Tree (CART) technique, ozone and meteorological data for 1712 days between 1996 and 2003 were analyzed. The CART analysis leads to a separation of days into "bins" of similar meteorological conditions and when paired with observations of ground-level ozone, it is possible to identify meteorological regimes that have a higher tendency to coincide with higher concentrations of ozone. For the years 1996 to 2003, each day was classified by its meteorology into one of 31 different bins. Additionally during this period, there were 294 days on which the 8-hour ozone NAAQS was exceeded at one or more monitoring stations in Georgia. In some meteorological classifications (i.e. bins), exceedances of the 8-hour ozone NAAQS were rare. In others, they occurred with more frequency. There was one bin, however, that contained far more exceedance days than any other. In this single bin alone, 65 (22%) of the 294 exceedances were observed. The next most frequent bin contained only 34 (12%) of the exceedance day events. One may conclude from this analysis that the meteorological conditions represented by this one bin are most often associated with exceedances of the 8-hour ozone NAAQS in Georgia, and it is from this pool of 65 days that we selected two meteorological episodes to use in our RSim AQM: 4 August 1999 and 7 August 1999 (Table 2). While these two days are not the worst days for ozone air quality, they are near the 8-hour ozone design value for 1999 (Figure 6), and thus are representative of the Columbus – Fort Benning area's air quality relative to the form of the NAAQS (i.e. the 3-year average of the 4th annual daily peak 8-hour average ozone concentration). It is from these episodes that the user can select from for χ_{base}. In the RSim AQM, however, these days are not actually represented directly. They are represented though the air quality model simulations of these days conducted during the Fall Line Air Quality Study (Change et. 2004). See for example, Figure 8.

Table 2. Atmospheric conditions on 4 August 1999 and 7 August 1999 in the Columbus – Fort Benning area.

*Columbus Metro Area**	*4 August 1999*	**7 August 1999**
Peak O_3 (ppb)	83	89
Prior Day Peak O_3 (ppb)	83	97
Max Temp (C)	34	37
Min Temp (C)	24	24
Average Dewpoint (C)	67.5	64.7
Average Wind Speed (mph)	3.4	3.7

* O_3 data from GA EPD at the Crime Lab and Airport stations, meteorological data from the NWS at the Airport station.

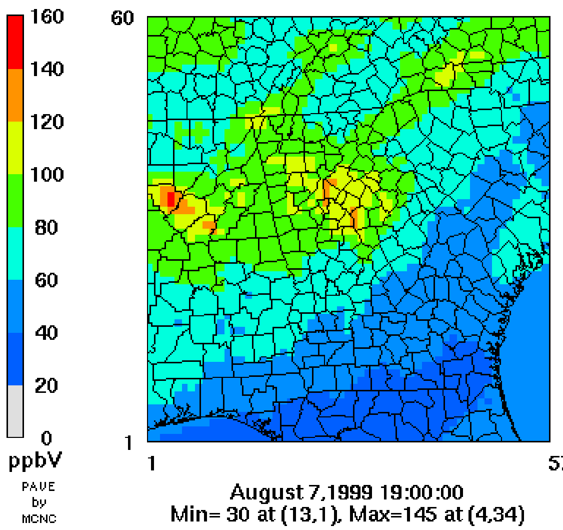


Figure 8. FAQS simulation of 8-hour ozone on 7 August 1999.

The air quality models of the Fall Line Air Quality Study are fully described elsewhere including evaluations of the model performance (Chang et al. 2004). It is sufficient to say here that the FAQS models are reasonable representations of air quality in the Fall Line cities of Georgia including Columbus. As a model though, there are differences between the simulated concentrations and observed concentrations that should be noted. For example, on 4 August 1999, the simulated peak 8-hour average ozone concentration in the Columbus area was 79 ppb rather than the

83 ppb that was observed. Similarly, on 7 August 1999, the simulated peak 8-hour average ozone concentration in the Columbus area was 81 ppb rather than the 89 ppb that was observed. Differences such as these are typical for almost all air quality models. Nonetheless, we "correct" for these differences in the RSim AQM by scaling the base and future model predicted values to the appropriate observed value. For example, using the mild ozone episode of 4 August 1999, the simulated peak 8-hour average ozone concentration is 79 ppb whereas the observed ozone concentration is 5% higher at 83 ppb. Thus, for this episode, all base and future year simulated ozone concentrations are scaled higher by 5%.

3.4.4.2 Base Emissions ($\mathbf{E}_{base}$)

Prior to the Fall line Air Quality Study (FAQS), the Columbus, Georgia area was never the focus of an air quality assessment and thus, no emission inventory had been specifically developed for the region. The area has been included peripherally in other large regional studies including the Ozone Transport Assessment Group (OTAG, US EPA, 1998)), the Southern Appalachian Mountain Initiative (SAMI), and the Gulf Coast Ozone Study (GCOS) but at a more coarse resolution than has been done in the FAQS. Here then, the emissions inventories developed for the FAQS (and fully described in Chang et al. 2004) are the bases for the inventories used in RSim.

Emissions are considered in five source categories: point, area, non-road, mobile, and biogenic. Point sources are large stationary industries such as coal fired power plants. Area sources are small stationary ventures and may include sources such as dry cleaners, gas stations, or residential water heaters. Non-road sources include construction, lawn and garden, railroad, and farming equipment. Mobile sources are limited to on-road vehicles, i.e. cars, trucks, and motorcycles. Finally biogenic sources are natural such as trees, crops, lightening, and soil microbes. Table 3 summarizes the base year (1999) emissions in the Columbus area and other metropolitan areas in Georgia.

Table 3. Episode average daily emissions during August 1999 (tons per day).

	Point		*Area*		*Non-road*		*Mobile*		*Biogenic*	
	NO_X	VOC	NO_X	VOC	NO_X	VOC	NO_X	VOC	NO	VOC
Augusta	18.73	7.00	3.24	37.38	9.68	6.70	33.93	22.88	2.90	435.12
Columbus	9.76	10.16	2.74	27.25	7.90	4.76	23.21	17.18	1.14	338.04
Macon	173.73	8.42	3.70	38.05	13.48	6.32	47.39	28.87	1.59	313.89
Atlanta	87.37	31.38	48.5	173.66	116.37	77.66	295.58	178.82	2.56	827.08
Georgia	829.98	135.41	111.41	711.44	310.7	188.9	846.98	525.38	64.97	11505.26

It is worth noting the sizable difference in biogenic VOC emissions relative to the other sources of VOCs. Eliminating all VOCs of human origin (i.e. point, area, non-road, and mobile), would have little effect on the total VOCs. Conversely, significantly increasing (e.g. doubling) VOC emissions from any human source would not substantially add to the total VOC load either. Thus, as a means to effect change in ozone concentrations ($NOx + VOCs + sunlight \rightarrow O_3$), VOC change is generally inconsequential. This is a well noted phenomenon for most of the southeastern U. S. (Chameides and Cowling, 1995), and it is for this reason that the RSim AQM focuses only on changes in NOx emissions and how those changes affect ozone concentrations.

3.4.4.3 Future Growth ($\mathbf{G}_{future}$)

To estimate how emissions will change in the future, emission growth factors for the Columbus, GA area are predicted using two EPA models: the Economic Growth Analysis System (EGAS, US EPA 2004a and 2004b) and NONROAD (US EPA 2006). EGAS "is an emissions activity forecast software model that provides State and local governments with an EPA-approved set of emissions activity growth factors [for point, area, and mobile sources]" (Bowman and Stella, 2001). The NONROAD model is a similar model dealing specifically with emissions from nonroad mobile engines, equipment, and vehicles. With these models it is possible to estimate emissions change for any year for any Source Classification Code (SCC)[c] in any county of the United States. EGAS Version 5.0 provides growth factors out to the year 2035, and NONROAD2005 provides growth factors out to the year 2050. One further point of distinction is that the NONROAD projections include the effects of some federally defined default controls on emissions (e.g. new rules limiting emissions from heavy duty diesel engines). The EGAS projections on the other hand, reflect only changes in future activity relative to the base year and do not include any projected controls on emissions from point, area, and mobile sources.

As implemented here, EGAS Version 5.0 and NONROAD2005 were run offline to generate growth rates for every SCC code for every year available. These growth rates were then aggregated into the broader categories of point, area, non-road and mobile sources by taking a weighted average for each source category based on the percentage of each SCC source in the county's total base year (1999) emissions. These average growth rates for point, area, non-road, and mobile sources are then used directly in the RSim AQM to grow the emissions for each source category in each county. For longer term growth projections that extend beyond the scope of growth factors provided by EGAS (i.e. out to the year 2035) or NONROAD (i.e. out the year 2050), a linear extrapolation is used.

One exception to using EGAS or NONROAD as the basis for growth factors is for prescribed burning. Neither model support growth factors for prescribed burning, so in the RSim AQM changes in prescribed burning activity are coupled to changes in forest land cover (LC):

$$G(\text{burning})_{future} = LC(\text{forest})_{future} / LC(\text{forest})_{base}$$

Further, since NOx emissions from prescribed burning accounts for 17% of base year emissions in the area source category, the overall area source growth factor is the weighted accordingly:

$$G(\text{AREA}) = 0.83*(\text{other area sources from EGAS}) + 0.17*G(\text{burning})$$

[c] Source Classification Codes uniquely identify different emissions sources in the point, area, non-road, and mobile source categories. The US EPA maintains a current database of SCCs at http://www.epa.gov/ttn/chief/codes/scc_feb2004.xls.

This combination of land cover surrogates for prescribed burning, and EGAS, NONROAD, and linear extrapolations thereof for all other emissions sources, represent the default emissions projections used by the RSim AQM. The module also allows the user additional opportunities to scale these projections up or down based on the user's own growth projections, ideas about future controls, or desires to evaluate the sensitivity of air quality outcomes to different emissions scenarios. On the Air Quality Module interface (see Figure 9), the user has the option of entering "Emission Growth Scaling Factors" for point, area, non-road, and mobile sources. The default scaling factors are 1.0, which means that the default emissions projections, as described above, will be used. Beyond the default, users may input any value from +2 to -2 for a growth scaling factor. The user should understand that the growth scaling factor scales the <u>rate</u> of emission change and <u>not the amount</u> of emissions directly. The effects of different growth scaling factors on the rate of emission change are summarized in Table 4. The effects of these scaling factors on the amount of emissions are shown in Figures 10 through 13.

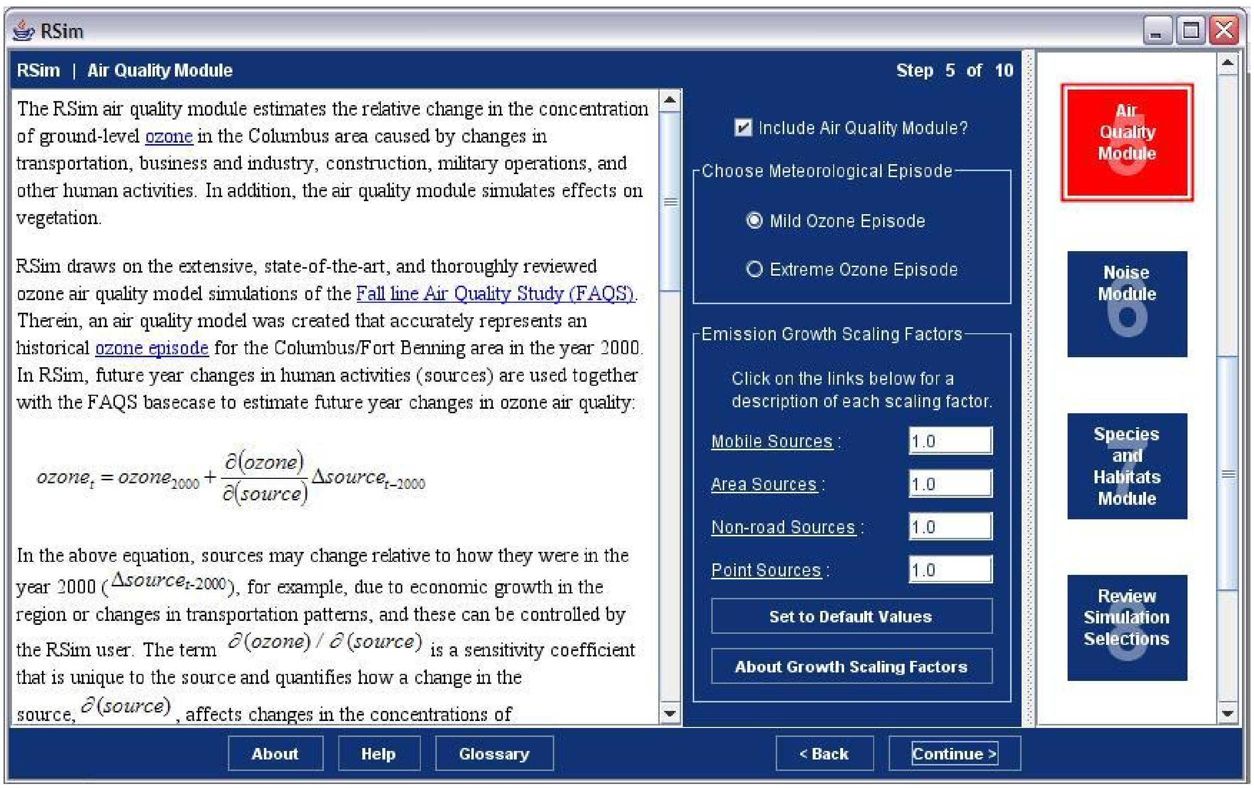


Figure 9. RSim Air Quality Module user interface.

Table 4. Effect of different emission growth scaling factors on rate of emissions change.

Emission Growth Scaling Factor, X	Future Emission Trend
1 < X < 2	Emission trend change greater than the default change in emissions
X = 1	Default change in emissions
0 < X < 1	Emission trend change smaller than the default rate of change
X = 0	No change in emissions over time
-1 < X < 0	Emissions change that is opposite of the default change and at a smaller rate
X = -1	Emissions change that is exactly opposite of the default rate of change
-1 < X < 2	Emissions change that is opposite of the default rate of change and greater

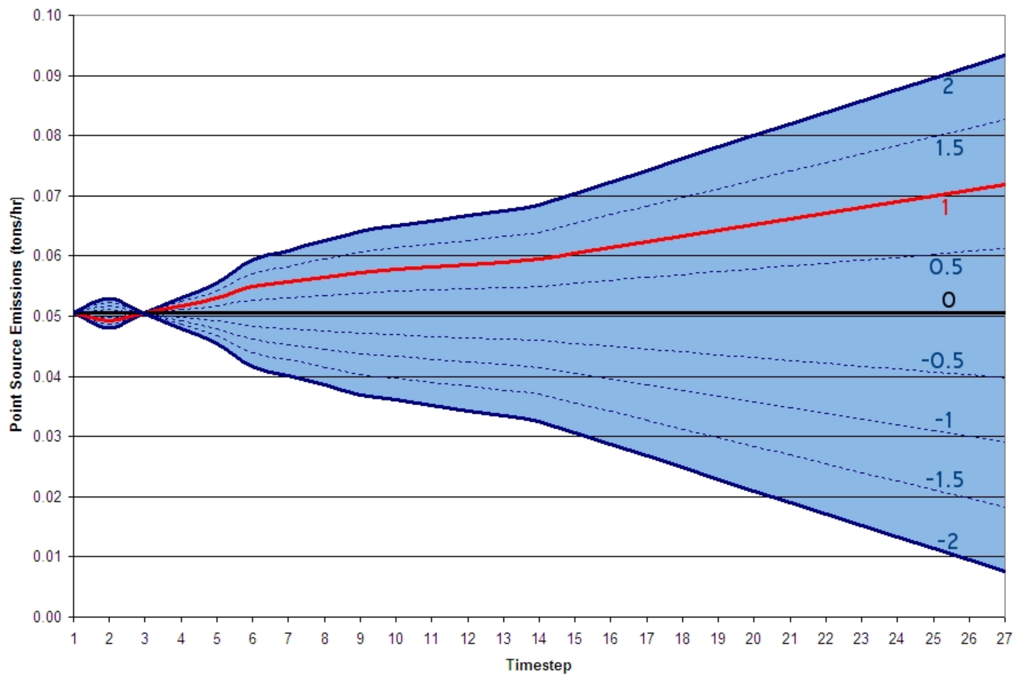


Figure 10. Effect of different growth scaling factors on emissions of point sources in the Columbus – Fort Benning area. Note: the default projection is for point source emissions to initially decrease; before year 4, negative scaling factors paradoxically increase emissions.

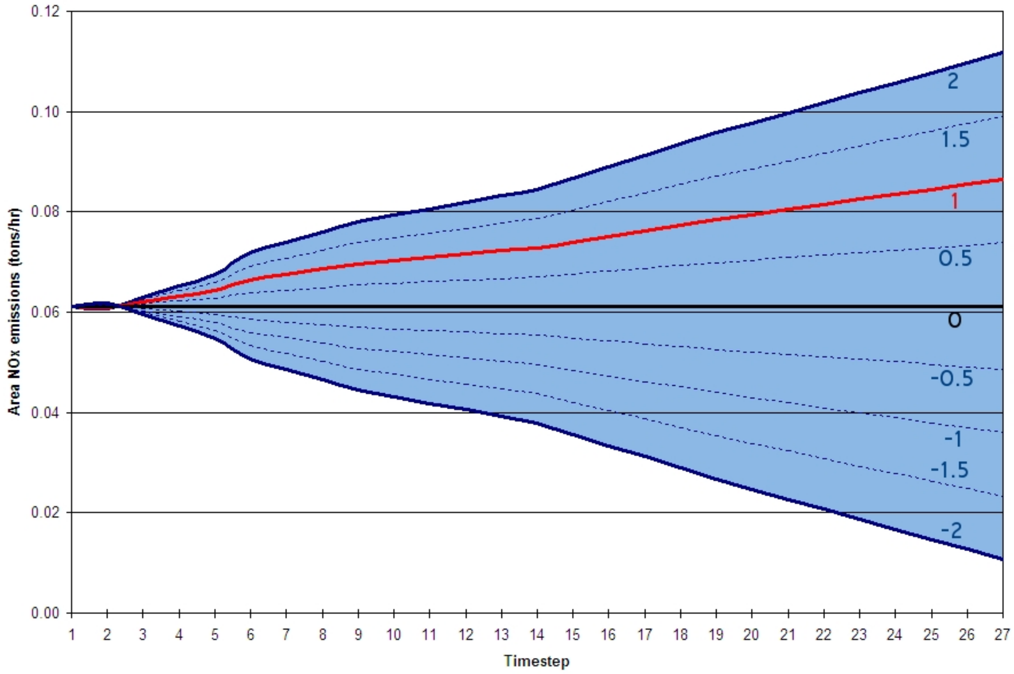


Figure 11. Effect of different growth scaling factors on emissions of area sources in the Columbus – Fort Benning area.

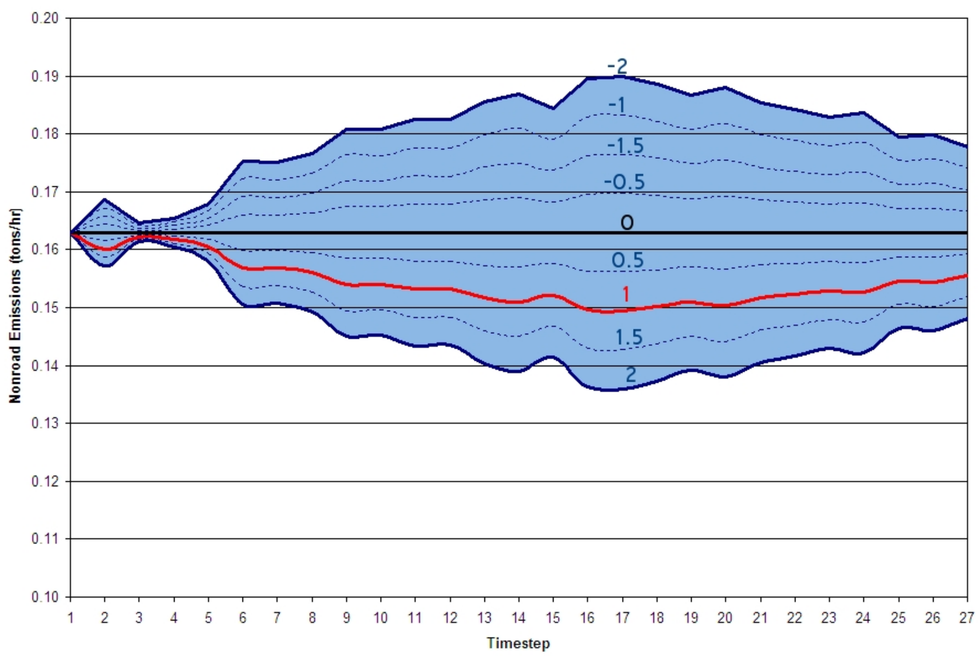


Figure 12. Effect of different growth scaling factors on emissions of nonroad sources in the Columbus – Fort Benning area. Note: the default projection is for nonroad source emissions to decrease and the user should notice that negative scaling factors increase emissions.

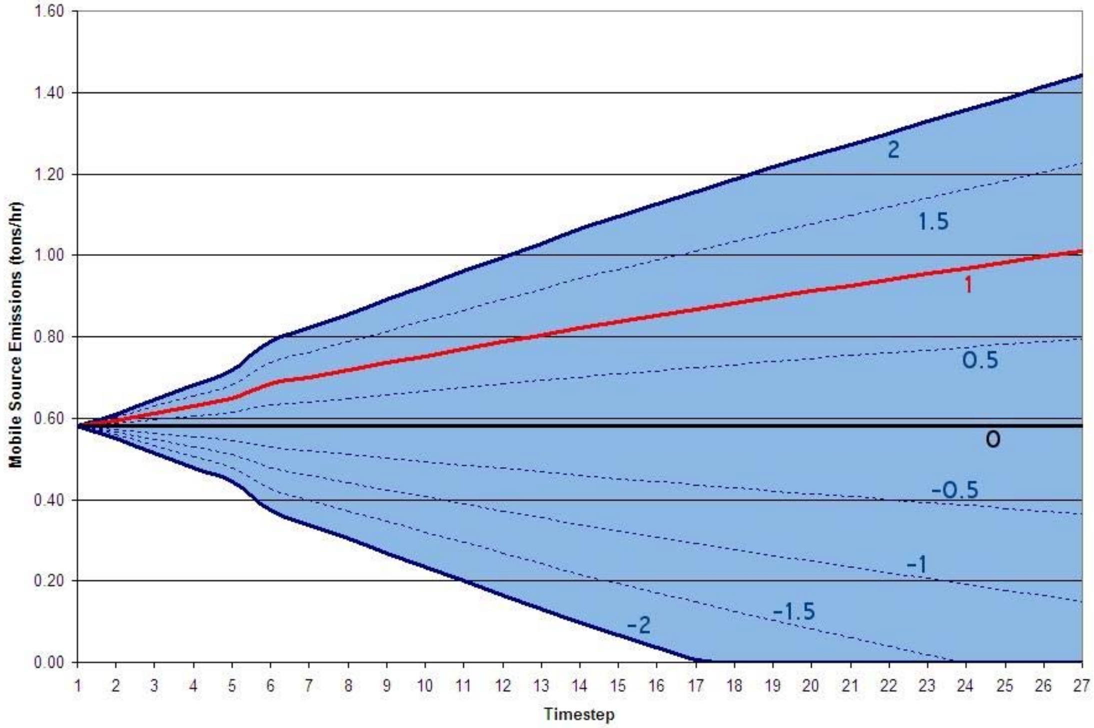


Figure 13. Effect of different growth scaling factors on emissions of mobile sources in the Columbus – Fort Benning area.

Example: Using Growth Scaling Factors

- Suppose a user expects that population growth will lead to an increase in vehicle miles traveled (VMT) in the Columbus area that is 25% higher than the default rate of increase. This can be simulated by changing the default emissions growth scaling factor for mobile sources from 1.00 to 1.25.
- Alternatively, suppose the user believes that automobiles will emit 50% less NOx per mile traveled in the future than they do now. This can be simulated by changing the default emissions growth scaling factor for mobile sources from 1.00 to 0.50.
- Finally, suppose that the user expects both an increase in VMT of 25% and a decrease in NOx emissions per mile traveled of 50%. This can be simulated by changing the default emissions growth scaling factor for mobile sources from 1.00 to 0.625 (i.e. 1.25 X 0.50)

3.4.4.4 Sensitivity Coefficients (**P**)

Sensitivity coefficients (S) measure the change in model response due to a change in some model parameter. Here, we are most interested in the change in ozone concentrations at location i, $(\Delta O_3)_i$, due to changes in emissions from source j at location k, $(\Delta E)_{jk}$.

$$S_{i,jk} = (\Delta O_3)_i / (\Delta E)_{jk}$$

These sensitivity coefficients can be readily and efficiently calculated using a comprehensive 3-dimensional photochemical grid model and were so done in the Fall Line Air Quality Study (Cohan et al. 2005, Chang et al. 2004).

Traditionally, sensitivities relate the impact of a change in emissions from a single source on air quality in many locations. For example, Figure 14 shows the response of ozone concentrations to emissions of NOx in the Columbus area. These types of sensitivity analyses would, however, require many model runs to determine the impact on air quality in a single location to emissions from many sources. Recent work at Georgia Tech to reinterpret traditional sensitivities has led to a new approach to define an area of influence (AOI) (Habermacher 2006, and Napelenok 2006). The AOI indicates how emissions across the domain impact air quality in a specific area. Figure 15 shows how potential NOx sources from across the region may affect air quality in Columbus. For the RSim AQM, it is these AOI coefficients that are used. Calculated external to the RSim AQM using the full FAQS air quality model, this array of sensitivities, **P**, relate changes in air quality at all locations i=1,m to changes in all sources j=1,n at all locations k=1,p.

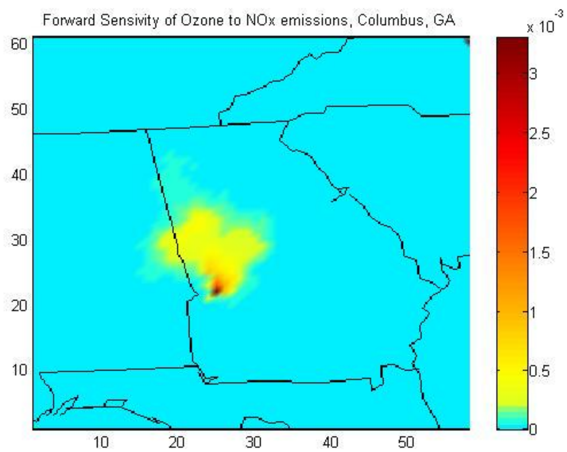


Figure 14. Ozone sensitivity to NOx emissions in Columbus, GA on 7 August 1999 (units are ppm O_3 per mole/s of NOx).

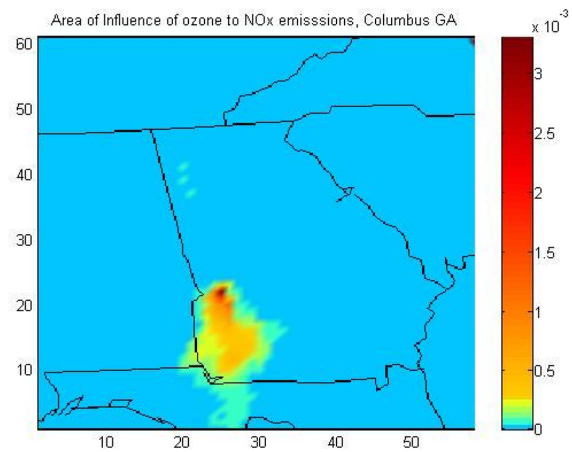


Figure 15. Area of Influence affecting ozone concentrations in Columbus, GA on 7 August 1999 (units are ppm O_3 per mole/s of NOx).

3.4.5 Integration of the AQM into RSim

The description of the Air Quality Module above is a highly simplified version of a stand-alone air quality model in which land use and land cover, as is typical for most air quality modeling applications, are assumed to remain constant. Assuming that land use and land cover remain constant is sufficient for most air quality modeling applications because they mostly deal with relatively short time frames (3 to 7 years) in which land use and land cover, at the regional scale at least, remains relatively unchanged. RSim, however, addresses longer time scales (25 years or more) in which significant land use or land cover changes may occur. Here we describe the three principal ways in which we have accounted for these potential changes and integrated the Air Quality Module into RSim.

In RSim, the urbanization and road development scenarios (using the default model coefficients) represent land use and land cover defaults, and for these default scenarios, future year growth or change in emissions are already accounted for by the EGAS projections described above. Variations from the defaults, however, will lead to increases or decreases in the various classes of land uses and land covers. We use variations in the transportation land cover class to further scale the mobile sources, the largest source of smog forming precursors in the RSim domain. For example, suppose that in the year 2020, EGAS projects that mobile source emissions will increase by 20% over 1999 emissions. This 20% growth rate is valid assuming the default urbanization and road development scenarios. If the model coefficients are changed by the user, however, such that in the year 2020 there is 10% less land covered by the roadway transportation class than in the default scenario, then the default growth rate in emissions should also be reduced by 10% resulting in an emissions growth rate of 18% (i.e. 20% - 10%*20%). Similarly, the selection of the military expansion scenario could also lead to a change in land cover for the transportation class and lead to changes in the mobile source emissions growth rate. (Note: the military expansion scenario may also lead to changes in the non-road mobile source emissions and this is dealt with separately as per below). The hurricane scenario does not affect the transportation land cover classes and so has no impact on mobile source emissions.

We assume the rate at which forest land cover that is burned each year under prescribed burning programs will remain constant over the modeling period. Therefore, we can tie future prescribed burning emissions directly to the change in total forest land cover as described by our calculations in the previous section. In RSim, the urbanization, road development, military training, and hurricane scenarios all modify the amount of predicted forest land cover and thereby impact our air quality forecasts.

Finally, the selection of the military training scenario may lead to additional non-road source emissions associated with the training activities themselves (e.g. heavy duty diesel vehicles, field generators, small or heavy arms, obscurants, etc.). As of October 2006, it is not yet understood what, if any, additional scaling factor may be required to account for any such changes in training activity, and so this connection has not been directly coded into the RSim AQM at this time. If this becomes known in the future, it is possible to approximate an increase in training activities by adjusting the emissions growth scaling factor for non-road sources as described in section 3.4.3.

In summary, changes in land cover or training activity can affect future year emissions from mobile sources, prescribed burning sources, and non-road mobile sources. By default, the AQM accounts for changes in prescribed burning activity by automatically scaling this source up or down with changes in forest land cover. The effects on air quality from changes in military training activity are not explicitly provided for in the AQM, but they may be approximated by making the appropriate adjustment to the non-road source emissions growth scaling factor. This leaves only the changes in the transportation land cover class unaccounted for in the AQM. Any such modifications (**L**) are applied to the growth factors (**G**) described above such that:

$$\chi_{future} = \chi_{base} + \mathbf{E}^{T}_{base}[\mathbf{L}^{T}\mathbf{G}_{future}]\mathbf{P}$$

where

L is a vector of modifiers to the growth factors that are derived from changes in the transportation land cover class:

$$LC(\text{transportation})_{\text{future,scenario } i} \,/\, LC(\text{transportation})_{\text{future,default scenario}}$$

Lastly, it should be noted that RSim recognizes that output from the air quality module can affect the ecology of the RSim domain by including language about ozone causing foliar damage in trees, crops, and other vegetation, as well as other effects. The output page includes a statement regarding the number of simulation years in which the secondary ozone standard is exceeded. Due to the variability of effects across the breadth of flora (and fauna), however, there is no way at this time to provide a more quantitative direct feedback into the RSim land cover (e.g. we could not code into RSim something akin to the following: for every 10 ppb increase in ozone, the forest land cover class will diminish by 1%). We expect such feedbacks to in fact occur, but are unable to justifiably quantify them at this time. Instead, we provide a qualitative statement to alert the user to such possible effects.

We have selected the ozone secondary standard (0.08 ppm) as the ecological risk threshold of importance in RSim. Numerous effects levels for particular crop and tree species are available in the current Ozone Criteria Document. Some thresholds for effects are expressed via the SUM06 metric (Sum of hourly ozone values greater than 0.06 ppm summed over 12 hours [0800-2000] during a 3-month growing season period) rather than ozone concentrations in air. For the Columbus, GA region, the 4th highest ozone concentration is tightly related to SUM06. The secondary standard of 0.08 ppm is close to a SUM06 value of 20 ppm-hrs. In 1996 the Emission and Effects Task Group of the Southern Oxidant Study Program recommended a secondary ozone standard of 15 to 20 ppm-hrs SUM06 in 1996 (Cowling and Furiness 2004), based on reductions in crop yield at this range, growth effects on natural forest trees (10-15 ppm-yrs), and growth effects on plantation trees (12-16 ppm-hrs). Thus, RSim's result that adverse effects on vegetation growth or yield are likely at 4th highest 8-hr ozone concentrations above 0.08 ppm should be reasonable.

3.5 Water quality and Nitrogen and Phosphorus Export

3.5.1. Introduction

The purpose of the water quality submodel is to predict changes in annual nitrogen (N) and phosphorus (P) exports from watersheds within the 5-county (Harris, Muscogee, Marion, Chattahoochee, Talbot) RSim region surrounding Fort Benning, Georgia. It is widely established that land use and land cover are principal determinants of nutrient export from terrestrial ecosystems to surface receiving waters. The water quality submodel predicts total (kg yr^{-1}) and normalized (kg ha^{-1} yr^{-1}) losses of N and P from 48 watersheds within the region over the time frame of RSim scenarios. Predicted changes in water quality are strongly coupled to future changes in land cover that result from urbanization, changes in agriculture, and disturbance events.

3.5.2. Approach

Calculations of annual N and P export are performed for the 48 12-digit hydrologic units (HUC) that are included within the RSim region (Figure 2). The method is based on land cover area (ha) within each watershed and annual nutrient export coefficients (kg element ha^{-1}) specific to each of the eight land cover types (Table 5). The area (ha) of each land cover category is multiplied by its respective export coefficient (Table 6) and the products are summed for all land covers to estimate the annual flux (kg element yr^{-1}) of N or P from each watershed. The exports (kg yr^{-1}) are also normalized for the size (ha) of the watershed to yield an area-normalized N or P export (kg element ha^{-1} yr^{-1}). The 48 12-digit HUCs range in size from approximately 3200 to 12000 ha.

3.5.2.1 Land Cover Classification

Twenty-eight different land cover categories, based on NLCD land cover class definitions, were reclassified into the following broad groups for use in the water quality submodel: (1) wetlands, (2) forests, (3) pasture/grass, (4) row crops, (5) idle, (6) industrial, (7) residential, and (8) business. Permanently or seasonally flooded land covers were classified as wetlands. Forests, other than swamps and forested wetlands, were grouped in a single category. Because of their association with industry, transportation corridors were binned with quarries and strip mines into a single industrial category. Other land cover classifications are described in Table 5.

3.5.2.2 Export Coefficients

Export coefficients have been widely used to predict total N and P losses from landscapes to surface receiving waters (e.g., Beaulac and Reckhow, 1982; Frink, 1991; Johnes, 1996; Mattikalli and Richards, 1996). An export coefficient is the amount of N or P lost annually from a particular land cover type on an area basis (for example, g N m^{-2} yr^{-1}). Export coefficients can be combined with information on the area of different land

Table 5. Reclassification of 1998 and 2001 land cover categories for RSim.

Reclassified land cover	1998 Land Cover (code)	2001 Land Cover (code)
Wetland	Open water (11) Forested wetland (91)	Open water (11) Woody wetland (90) Herbaceous wetland (95)
Forest	Deciduous (41) Evergreen (42) Mixed (43)	Deciduous (41) Evergreen (42) Mixed (43)
Pasture	Pasture (80)	Pasture (81) Grassland (71)
Idle	Beach (7) Utility swaths (20) Clear-cut/sparse vegetation (31)	Shrub (52) Barren land (31)
Industrial	Transportation (18) Quarries and strip mines (33)	
Residential	Low intensity urban (22) Parks and recreation (72)	Developed, open space (21) Developed, low intensity (22) Developed, medium intensity (23)
Row crops	Row crops (83)	Cultivated crops (82)
Business	High intensity urban (24) Golf courses (73)	Developed, high intensity (24)

Table 6. Export coefficients for N and P from different land cover categories (from Osmond et al., 1995, and CH2M HILL, 2001).

Revised land cover	Export coefficient	
	kg N ha^{-1} yr^{-1}	kg P ha^{-1} yr^{-1}
Wetland	5.5	0.25
Forest	1.8	0.11
Pasture	3.1	0.1
Idle	3.4	0.1
Industrial	4.4	3.8
Residential	7.5	1.2
Row crops	6.3	2.3
Business	13.8	3.0

uses and/or land covers to predict the annual flux of N and P from terrestrial watersheds. Past studies that have compared predicted and measured nutrient loads appear to validate the use of export coefficients for estimating annual watershed losses of both N and P (Johnes, 1996; Johnes et al., 1996; Mattikalli and Richards, 1996).

Within certain limits, export coefficients for the 8 different land cover categories in the water quality model can be adjusted to the user's specifications. The lower limit for each category is 0 kg element ha^{-1}. The upper limit is twice the default value. Selecting different parameter settings within the allowed range permits the user to examine the sensitivity of predicted N and P exports to changing export coefficients.

Default export coefficients for total N and P from all land covers except row crops and wetlands (Table 6) were adopted from the North Carolina State University (NCSU) WATERSHEDSS Pollutant Budget Estimation Form that is part of the NCSU WATERSHEDSS Decision Support System for Nonpoint Source Pollution Control (Osmond et al., 1995). Default export coefficients for wetlands were taken from a different source (CH2M HILL, 2001).

Default export coefficients for row crops were calculated as a weighted mean based on (1) crops planted in the 5-county region and (2) export coefficients for specific crop types from the WATERSHEDSS Decision Support System (Table 7). Data from the USDA, National Agricultural Statistics Service, Agricultural Statistics Database on acres of major crop types planted from 1996 to 2000 were compiled for each county in the RSim region. There were no reports for Chattahoochee and Muscogee counties that are mostly occupied by Fort Benning. Peanuts, rye, wheat, soybeans, corn, and cotton were the major crops in the 3 remaining counties. Based on a 5-year average, small grains (e.g., wheat and rye) were planted on ≈44% of the region's agricultural land. Cotton, corn, soybeans, and peanuts were ≈8, 12, 15, and 20%, respectively, of the acres planted. The export coefficient for N from peanuts was set to zero (Table 7). Peanuts are a legume and usually receive no N fertilizer because they are sensitive to fertilizer burn. The weighted average export coefficient for N and P from row crops in the RSim region was 6.3 kg N ha^{-1} yr^{-1} and 2.3 kg P ha^{-1} yr^{-1}, respectively (Table 6).

Table 7. Export coefficients for N and P for different agricultural crops (data for corn, cotton, soybeans, and small grains are from Osmond et al., 1995).

Crop type	Export coefficient	
	kg N ha^{-1} yr^{-1}	kg P ha^{-1} yr^{-1}
Corn	11.1	2.0
Cotton	10.0	4.3
Soybeans	12.5	4.6
Peanuts	0	1.5
Small grain	5.3	1.5

3.5.3. Water Quality Outputs

RSim predictions of N and P exports (kg element yr^{-1}) over time will vary depending on the changing patterns of land cover within each watershed. Trial runs with the water quality submodel indicate that the annual fluxes of both N and P exhibit a significant ($P \leq 0.001$) positive correlation with size of the hydrologic unit ($r = 0.80$ and $r = 0.48$, respectively). However, size of a watershed, the types of land cover within a watershed, and the export coefficients selected for different land covers all influence predicted N and P exports.

The total area of the 48 hydrologic units in the RSim region is 3570 km^2. Normalized for land area, and based on 2001 land cover, trial runs with the model indicate the predicted regional N and P export is ≈238 and ≈42 kg km^{-2} yr^{-1}, respectively. These predictions need to be verified and revised using the actual RSim model once it is fully operational.

Calculated nutrient exports for the 5-county RSim region can be put into perspective using data from other regional studies. Average N export from minimally disturbed watersheds in the U.S. is ≈260 kg N km^{-2} yr^{-1} and is strongly related to annual runoff (Lewis, 2002). Nitrogen export from the Mississippi, Hudson and Delaware Rivers (3 major eastern U.S. tributaries) has been estimated at ≈177, 356, and 518 kg N km^{-2} yr^{-1}, respectively (Caraco and Cole, 1999). Median N export from 16 rivers draining large watersheds (475 to 70189 km^2) in the northeastern U.S. over a 5-year study was 518 kg N km^{-2} yr^{-1} (Alexander et al., 2002). Total N and P export in rivers from the southeastern U.S. has been estimated to be ≈675 and ≈32 kg km^{-2} yr^{-1}, respectively, by Howarth et al. (1996). Predicted N export from the 5-county RSim region (238 kg N km^{-2} yr^{-1}) was in the lower range of reported exports for U.S. rivers and approximately twice that (111 kg N km^{-2} yr^{-1}) for a minimally disturbed watershed (Falling Creek) in central Georgia (Lewis, 2002). Predicted regional P export (42 kg km^{-2} yr^{-1}) agreed reasonably well with previously reported export in the southeastern U.S.. The relatively small percentage of cropland (range 0 to 17%) in the 48 watersheds inside the RSim region is one likely reason why predicted N export is in the lower range of N loadings reported by other studies from the eastern U.S. Export coefficients applied to agricultural land are greater than those applied to forests for both N and P (Beaulac and Reckhow, 1982; Frink, 1991).

Aside from the effect of agricultural land use on N export from the land to surface receiving waters, reviews of export coefficients for both N and P indicate the importance of urban development (Beaulac and Reckhow, 1982; Frink, 1991). A recent analysis of 35 large river systems from around the world indicates that river N export exhibits a significant positive correlation with population density (Caraco and Cole, 1999). Urbanization and commercial development along the perimeter of Fort Benning and in surrounding counties (Dale et al., 2005) have the potential to alter future exports of N and P from the 48 watersheds within the RSim region. Population growth, road improvements, and increasing urban land cover are key drivers in various scenarios that are addressed by RSim.

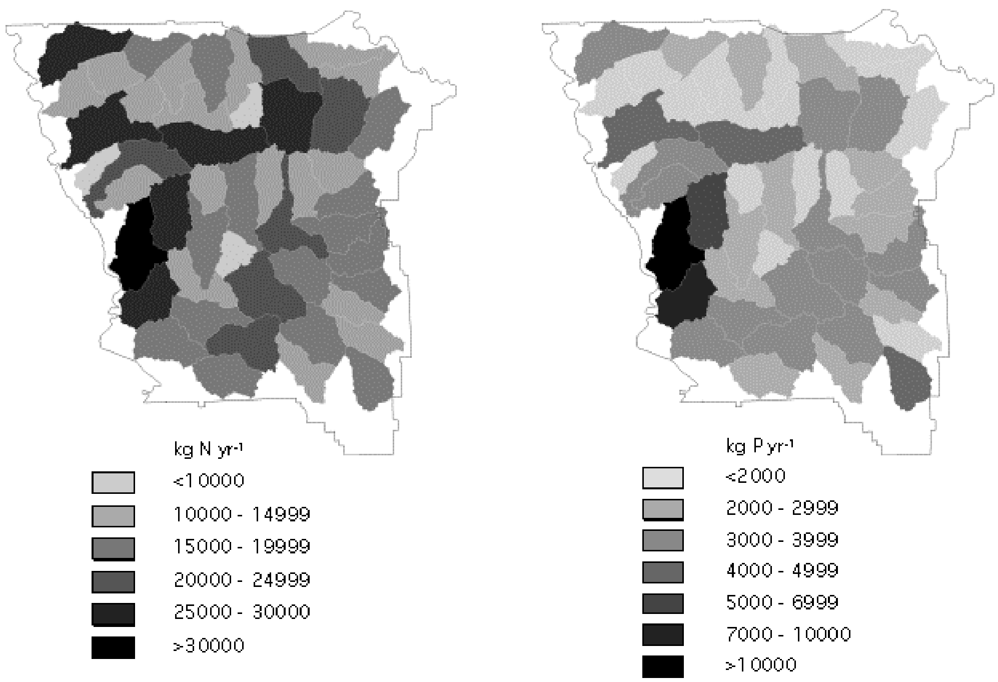


Figure 16. Predicted annual total N export (left panel) and P export (right panel) from 48 12-digit hydrologic units within the 5-county RSim region based on 2001 land cover data.

3.6 Noise in RSim

3.6.1 Noise

The principal way that noise impacts on wildlife have been studied in the past is through field studies at specific sites, where noise levels are measured in conjunction with measures of animal behavior or reproduction, usually at nest or burrow locations. Through the noise and risk assessment components of RSim, we plan to estimate impacts of noise on wildlife at Fort Benning without conducting any new field studies, with the acknowledgment that any uncertainties in field data will be transferred to model outputs. We have anticipated that exposure-response relationships for noise would include:

1. The transferal of effects thresholds from other sites and species to related wildlife at Fort Benning;

2. Use of GIS to infer apparent noise thresholds for particular species, based on overlaying noise contours on species presence/absence maps; and/or
3. Addition of noise to an existing habitat model to determine if including noise as a variable improves predictions.

We have made progress on the noise component of RSim in the past calendar year. CHPPM generated peak noise contours for blast noise at Fort Benning, both before and after construction of the Digital Multipurpose Range Complex, using the BNOISE model. We converted these files to grid maps in ArcView. Fort Benning staff provided us with survey data for many wildlife species, including deer harvest data, quail harvest data, rare species survey data (bald eagle, wood stork, American alligator), and LCTA data. We already had RCW nest locations and gopher tortoise burrow locations from Fort Benning, as well as gopher tortoise burrow predictions for the region from our habitat model. Unfortunately, nest or burrow locations are not available for other species. We have plotted survey data for groups of species on noise contour maps, and many of these locations are in high-blast-noise areas, but because these surveys were not tied to range activities, it is unclear if animals were present during times of high blast noise. Therefore, the noise component of RSim will be limited to our focal species, RCW and gopher tortoise. For future implementations of RSim, it is important that nest or burrow locations be surveyed, as these are the most long-term, reliable indicators of effects from noise (based on method 2 above) for species whose behavior has not been specifically studied in relation to noise and for which audiograms are not available.

3.6.2 Noise and RCW

The primary exposure metrics for noise are the peak noise contours mentioned above, as well as day-night average sound levels that were calculated prior to this year. In the near future, we may also simulate sound using a downy woodpecker weighting, a surrogate for RCW. It should be noted that the primary use of noise contours is in land-use planning zones. The use of these values in a simulation model like RSim raises uncertainties regarding units that are a challenge to overcome. However, noise contours are the best available estimate of exposure to noise for use in a regional model.

Thresholds for effects of sound on RCW will be taken primarily from Delaney et al. (2002). These thresholds have been checked, and some have been modified, in response to a comment at the SERDP in-progress review (Table 8).

Table 8. Risk assessment outputs for red-cockaded woodpecker (RCW) that are under consideration for use in RSim.

Stressor	**Exposure**	**Effect**	**Relevance to endpoint**	**Threshold**	**No Observed Effects Level**	**Reference**
Blast noise	artillery simulator in experimental test	Flushing from nest	Ft. Stewart population of RCW	91.4 m distance, 74-101 dB SEL[1,2]	152.4 m distance 65dBW SEL, 72 dB SEL unweighted	Delaney et al. 2002
Continuous noise	.50 caliber blank fire in experimental	Flushing from nest	Ft. Stewart population of RCW	121.9 m distance, 84-89 dB SEL[3]	152.4 m distance, 68 dBW, 80	Delaney et al. 2002

	test				dB unweighted	
Continuous noise	Small-caliber (M-16) live fire event	Flushing from nest	Ft. Stewart population of RCW		400 m distance, 51 dbW SEL, 76 dB unweighted SEL	Delaney et al. 2002
Continuous noise	Military helicopter overflights	Flushing from nest	Ft. Stewart population of RCW		30 m distance, 84 dBW SEL, 102 dB unweighted SEL	Delaney et al. 2002
Continuous noise	Large-caliber live fire event	Flushing from nest	Ft. Stewart population of RCW	500-600 m distance 77-79 dBW SEL; 105-108 dB SEL unweighted sometimes	700 m SEL, 59dBW SEL, 102 dB SEL unweighted	Delaney et al. 2002
Continuous noise	Military/civ-ilian vehicles	Flushing from nest	Ft. Stewart population of RCW	15-30m, 58-110 dB SEL unweighted, 56-91 dBW SEL	>50 m distance, <55dBW SEL, 75 dB SEL unweighted	Delaney et al. 2002
Blast noise	Missile launches	Flushing from nest	Ft. Stewart population of RCW		750 m, 25 dBW SEL, 69 dB unweighted SEL	Delaney et al. 2002
Blast noise	Grenade simulator	Flushing from nest	Ft. Stewart population of red-cockaded woodpecker	100 m, 92-95 dB SEL unweighted, 78-84 dBW SEL unweighted	200 m, 47dBW SEL, 82 dBW unweighted SEL	Delaney et al. 2002
Continuous noise	Fixed wing aircraft	Flushing from nest	Ft. Stewart population of RCW		600 m, 62 dBW SEL, 90 dB SEL unweighted	Delaney et al. 2002
Continuous and blast noise	Firing of small arms and artillery	Numbers of eggs, nestlings, adults, return rates of adults feeding young, masses of nestlings and adults	Ft. Benning population of RCW		82 dB Lmax, but control noise at similar level	Doresky et al. 2001, Nature Conserv-ancy of Georgia 1996
Habitat fragmentation	Simulated, fragmented landscapes	Population crash—Allee effect	Simulated North Carolina Sandhills population of RCW	Randomly distributed and moderately clumped populations of 25 groups, and randomly	Populations of 25 territories stable when territories were highly aggregated, moderately	Schiegg et al. 2002

				distributed populations of 100 groups declined	clumped populations of 100 groups were stable	
Habitat fragmentation	Simulated demograph-ic and environ-mental stochasticity	Population crash—Allee effect	Simulated North Carolina Sandhills population of RCW	Populations of 25, 49, 100 territories ranged from rapidly declining to stable depending on territory density and level of aggregation	Populations of 250, 500 territories stable regardless of level of territory aggregation	Walters et al. 2002
Habitat fragmentation	Spatial distribution of territories	Population crash—Allee effect	Simulated North Carolina Sandhills population of RCW	Populations of 169 or fewer highly dispersed territories	Populations of 49 or more highly aggregated territories	Letcher et al. 1998
Habitat fragmentation	Loss of territories	Population crash—Allee effect	General population of RCW	Less than 400 territories	400 territories	USDA 1995, U. S. Army 1996

[1]Range of values associated with distance LOAEL; distance at which RCW flushed only 1/16 times discounted from LOAEL but not included in NOAEL
[2] Dose-response relationship between stimulus distance and flush frequency is available.
[3]Range of values associated with distance LOAEL; no significant decrease in effect with distance

Table 9 shows some of the disconnects between units of exposure and units of effects that are being resolved in the coming weeks. Conversions have been checked with Larry Pater and/or David Delaney at CERL.

Table 9. Differences in units of exposure and effect levels for noise for RSim implementation at Fort Benning.

	Exposure	Effect level
Blast noise—large caliber	Unweighted Peak sound level contours CDNL 3) downy-woodpecker-weighted contours (possible)	Unweighted SEL for RCW flushing/not flushing from nest
Small arms	ADNL	Unweighted SEL for RCW flushing/not flushing from nest
Helicopter	ADNL for total aircraft	Unweighted SEL for RCW not flushing from nest
Fixed wing	ADNL for total aircraft	Unweighted SEL for RCW not flushing from nest
	Peak sound level contours	Peak sound level for desert tortoise (surrogate for gopher tortoise) not exhibiting acoustic threshold shift

3.6.3 Noise And Gopher tortoise

Effects of noise on gopher tortoise have not been tested in the field at Fort Benning or elsewhere. Therefore, the noise module of RSim will only be able to infer effects of noise, based on studies of related species or based on relationships between noise and burrow locations. While behavioral effects on desert tortoise were primarily due to sonic booms (Bowles et al. 1997a, not relevant to Fort Benning), we may use a peak sound level, no effects level for temporary hearing loss in desert tortoise from simulated aircraft overflights. Regarding noise and burrow locations, we plan to include noise as a variable in the gopher tortoise habitat model and simulate probable burrow locations based on noise as a variable.

3.6.4 Peak Noise Grids for Fort Benning

Catherine Stewart provided the 2003 operational data used to create peak noise contours for Fort Benning. Using the NOISEMAP software, closely spaced peak noise contours were created by setting the contour with primary grid spacing as 1, and setting 10 secondary grid spacings between the primary contours. These contours were then converted to a shape file and brought in to ArcView®. Using the contourgridder script (http://arcscripts.esri.com/details.asp?dbid=12531), the contours were converted to a 30 m grid dataset. Figure 17 illustrates the peak noise contour grids for 2003.

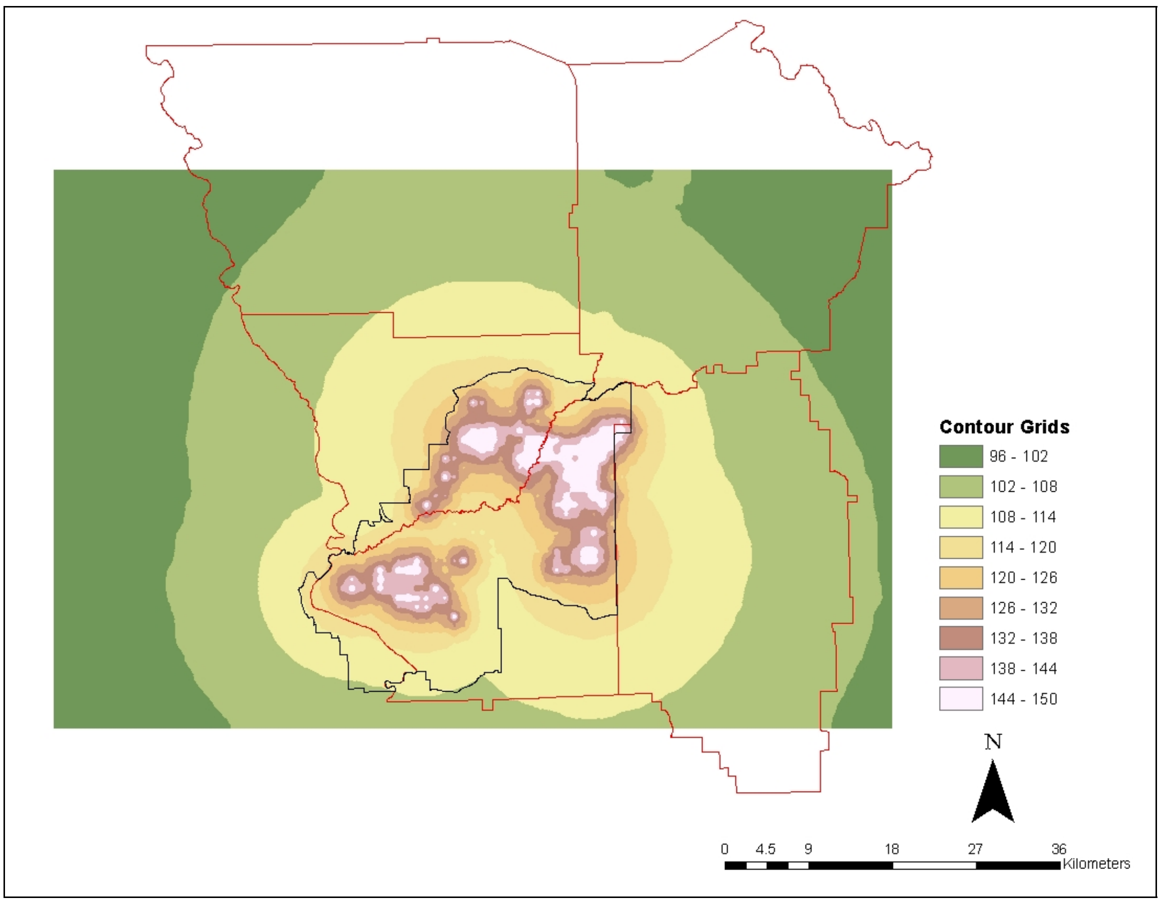


Figure 17. Peak noise contour grids for Fort Benning

3.6.5 Other Noise Contours Data Sets

Figure 18. Annual noise contours for Fort Benning in 2003 (source: CHPPM)

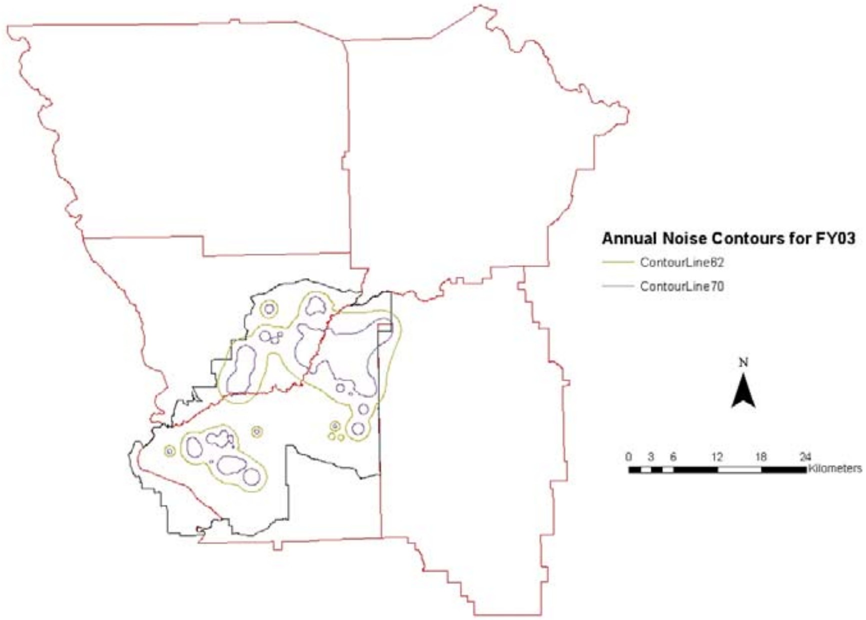


Figure 19. Noise contours for Fort Benning with the Digital MultiPurpose Range Complex (DMPRC). (source: CHPPM)

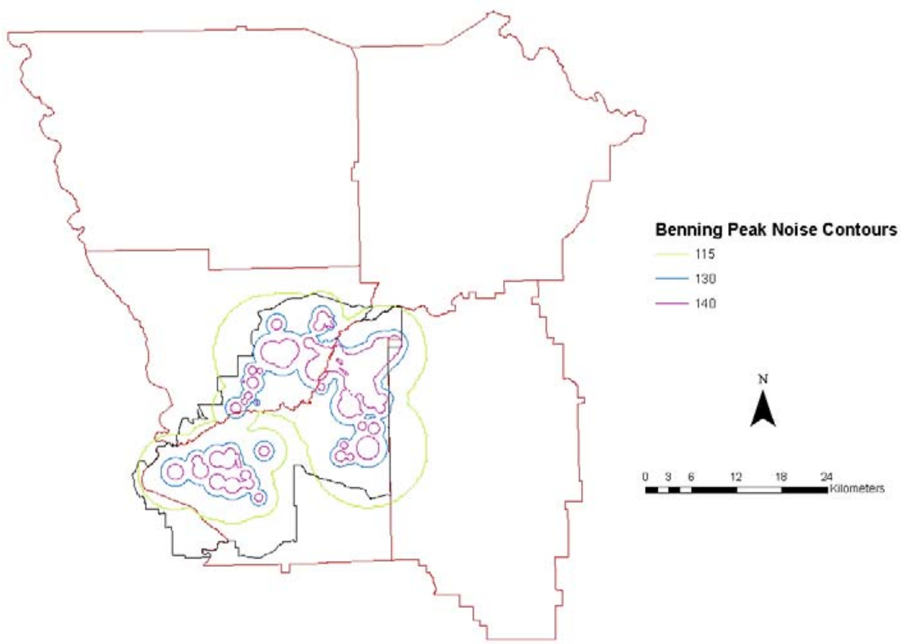
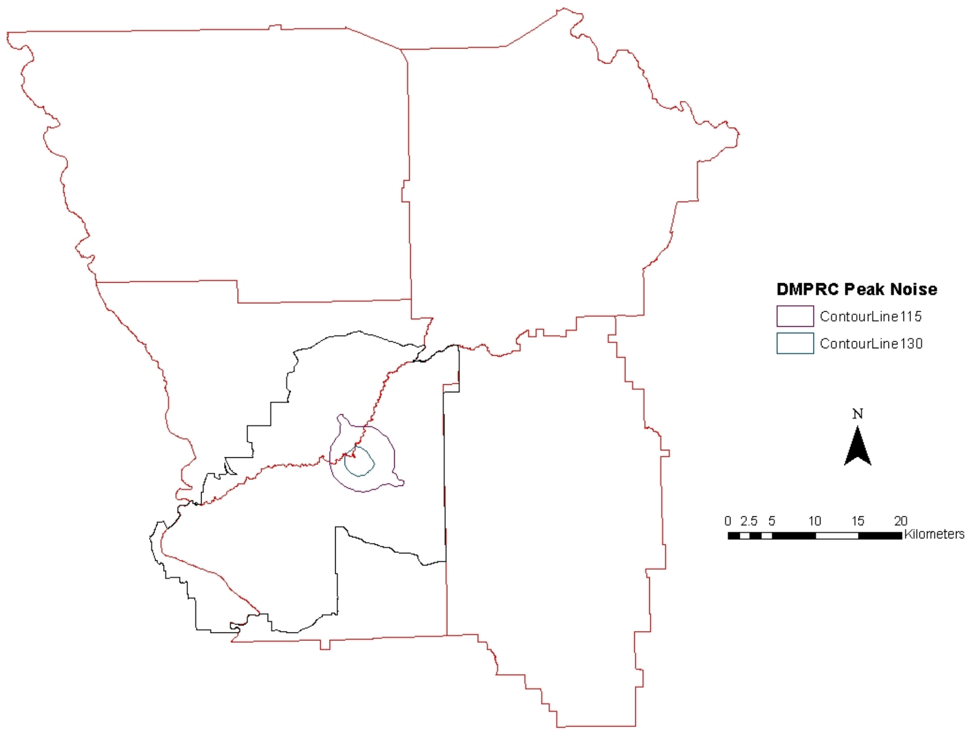


Figure 20. Peak noise contours for DMPRC. (source: CHPPM)



Adequate noise thresholds for behavioral or reproductive effects are not available for gopher tortoise or red-cockaded woodpecker. Therefore, we have replaced ecological risk assessment output for noise simulations in RSim with human annoyance output. These thresholds are based on Larry Pater's Blast Noise Guidelines that are likely to be adopted as new Army regulations (Table 10)

Table 10. Blast Noise Guidelines (from Pater 1976)[1].

Predicted Sound Level, dBP[2]	Risk of Complaints
< 115	Low risk of noise complaints.
115 – 130	Moderate risk of noise complaints.
130 – 140	High risk of noise complaints, possibility of damage
> 140	Threshold for permanent physiological damage to unprotected human ears. High risk of physiological and structural damage claims.

[1] Pater, L. 1976. "Noise Abatement Program for Explosive Operations at NSWC/DL", presented at the 17th Explosives Safety Seminar of the DOD Explosives Safety Board and presented in fact sheet at http://chppm-www.apgea.army.mil/dehe/morenoise/TriServiceNoise/document/DoDFS.pdf

[2] peak decibels

3.7 Species at Fort Benning

The focus of RSim is on the rare species: gopher tortoise (see Baskaran et al. 2006) and red-cockaded woodpecker (see below). Data on several more common species at Fort Benning were collected and analyzed to check if they could be used to study noise impacts on wildlife using the RSim model. Survey information on locations and habitats of several species were collected from the Integrated Natural Resources Management Plan (INRMP) of Fort Benning and communication with Fort Benning personnel. However it was found that none of these species had sufficient information to be able to identify noise related impacts. A listing of the species data currently available in Fort Benning, and their shortcomings (with respect to analyzing noise related effects) is provided in section 3.8.

We have incorporated an ecological patch size threshold for gopher tortoise. Mature individuals in Florida have been observed to abandon habitat patches of less than 2 ha (McCoy & Mushinsky 1988). The RSim user can select the size of the threshold patch area, but the default value is 2 ha.

RSim output for red-cockaded woodpecker is expressed with respect to the breeding cluster number goal (361) set forth in the FWS Biological Opinion and the Installation RCW management plan.

3.7.1. Gopher tortoise

Changes in habitat are often a major influence on species distribution and even survival. Yet predicting habitat often requires detailed field data that are difficult to acquire, especially on private lands. Therefore, Baskaran et al. (2006) developed a model that builds on extensive data that are available from public lands and extends them to surrounding private lands. This model was applied for a five-county region in Georgia to predict habitats for the gopher tortoise (*Gopherus polyphemus*), based on analysis of documented locations of gopher tortoise burrows at the Fort Benning military installation in west central Georgia. Burrow associations with land cover, soil, topography and water observed within the military installation were analyzed with binary logistic regression. This analysis helped generate a probability map for the occurrence of gopher tortoise burrows in the five-county region surrounding Fort Benning. Ground visits were made to test the accuracy of the model in predicting gopher tortoise habitat. The results showed that information on land cover, soils, and distances to streams and roads can be used to predict gopher tortoise burrows. This approach can be used to better understand and effectively carry out gopher tortoise habitat restoration and preservation activities.

3.7.2 Red Cockaded Woodpecker (RCW) and Longleaf Pine Habitat

The habitats for RCWs were identified from three sources:

- Hugh Westbury of Fort Benning, GA provided the location of RCWs within Fort Benning
- Jonathan Ambrose, Program Manager, Georgia Natural Heritage Program provided site specific information on the occurrence of RCWs as shape files. Only one location was identified by this data in Talbot County.

- Personal communication with Thomas Greene, The Nature Conservancy, helped to identify a few areas of longleaf pine strands. The locations were identified on a map of Fort Benning and the 5 counties. They were later digitized as points using ArcView 3.1 to make a shape file.

The above three sources of data were combined to create the layer of RCW habitat (Figure 21).

Longleaf pine habitats have been obtained from the following sources:

- SEF database – Neil Burns from EPA provided the Southeastern Ecological Framework data which had a layer for locations of longleaf pine for the whole of the Southeastern region.
- Callaway Gardens – LuAnn Craighton, Director of Stewardship at Callaway Gardens might be able to give specific locations of longleaf pine data within Callaway gardens. A project is underway for this, and is expected to be carried out in winter.
- GA GAP Alliance level mapping – The Alliance level mapping results will include a longleaf pine unit. This data will be useful to identifying the habitat within RSim study region.

Most of the RCW and longleaf pine habitat in the five country region fall within Fort Benning. Not surprising, RSim projections show that risk of change to these habitats is greatest due to activities within the installation.

RSim output for red-cockaded woodpecker is expressed with respect to the breeding cluster number goal (361) set forth in the FWS Biological Opinion and the Installation RCW management plan.

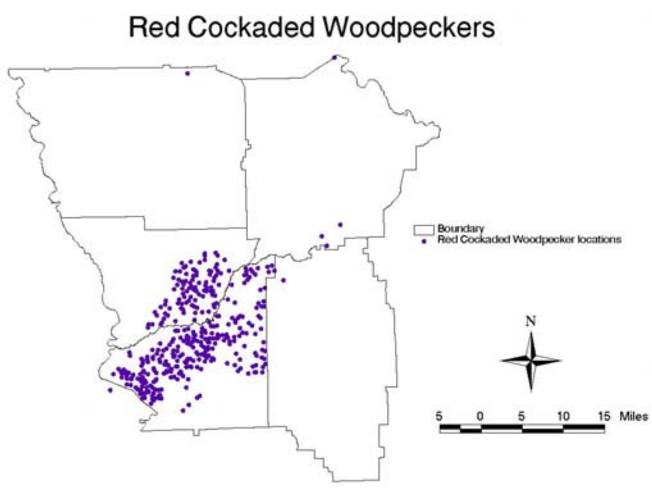


Figure 21. Location of red-cockaded woodpeckers in the study region.

3.8 Evaluation of Species Susceptible to Noise at Fort Benning

3.8.1 Introduction

Data on several common species at Fort Benning were collected and analyzed to determine if they could be used to evaluate noise impacts on wildlife using the RSim model. Survey information on locations and habitats of several species were collected from the Integrated Natural Resources Management Plan (INRMP) of Fort Benning and communication with Fort Benning personnel. However it was found that none of these species had sufficient information to be able to identify noise related impacts. A listing of the species data currently available in Fort Benning, and their shortcomings (with respect to analyzing noise related effects) is provided below:

3.8.2 Data available on species in Fort Benning

- Wood Stork, Bald Eagle and American Alligator: Since these species are fairly specific in the types of habitat they prefer, their locations are known in Fort Benning (mostly down in the backwaters of the Chattahoochee river) (personal communication with Rob Addington, Fort Benning, GA). However there is no data on their distribution or movement patterns within that habitat. For bald eagle, there is one nest along the river that is monitored for activity and breeding status. Wood stork is a transient species that tends to return to the same ponds year after year. Hence spatial data for these species is just a dot on the map showing the location of the nest or pond location. The same is the case for American alligators as well.

- Songbirds: Data on songbirds were available from the LCTA report.

- Birds and Mammals data from the LCTA report: The LCTA report represents a summary of wildlife data collected from 1991 through 1995 on sixty Land Condition Trend Analysis (LCTA) wildlife core plots at Fort Benning. The surveys include winter inventories of birds and small mammals and spring inventories of birds.

The numbers of bird and mammals sightings per plot are available in an access database. Information on a few relevant species and orders were extracted from the database and displayed in ArcMap. The species locations were overlaid on the noise grid and any possible associations with high or low noise levels was checked for (Figures 22, 23, and 24). The following information from Neil Giffen, Oak Ridge National Laboratory was used to identify some key species that may be affected by noise in Fort Benning.

- Waterfowl: Large flocks of waterfowl (ducks and geese) congregated on refuges have been known to flush as the result of low flying military aircraft. Waterfowl are most often noted in the literature as being particularly impacted by aircraft overflights. There are numerous accounts on National Wildlife Refuges. Similar behavior has been seen in areas with large congregations of shorebirds.
- Colonial Waterbirds: Based on the LCTA list of species, there may be some colonial waterbird (egret and/or heron) colonies on the installation. Some studies in Florida have

shown that low altitude military training flights had no impact on the establishment, size or reproductive success of the colonies. However, there is speculation that reductions in colonies of magnificent frigatebirds at the Key West National Wildlife Refuge may be due to frequent flyovers of tour planes coupled with low altitude military overflights. So, flights of military aircraft over any existing egret/heron rookeries could be a concern at Fort Benning.

- Gamebirds: A study done on the reaction of wild turkeys to sonic booms showed a limited alarm response not severe enough to result in decreased productivity.
- Passerine Bird Species: For some studies conducted on common passerine species, measurements of nesting success between habitats subjected to military overflights and control areas were not appreciably different. Also, species richness and abundance did not show appreciable differences. (The Bachman's sparrow, listed as rare in the state of Georgia, is present at Fort Benning according to the list and would be a species of concern)
- Raptors: The swallow-tailed kite is listed as rare in Georgia. Fort Benning appears to be a bit north of its breeding range. Studies done on snail kites in southern Florida found no evidence that overflights from nearby airports had adverse impacts on breeding success and behavior. Similarly, a four year study conducted by the USFWS on bald eagles in Arizona showed no adverse impacts to breeding bald eagles due to overflights of small propeller aircraft and helicopters. Also, ospreys in frequently overflown areas appear to habituate to the activity; however, flight/fright behavior has been seen in nesting ospreys in areas with only infrequent overflights.
- Studies of raptors in Colorado did show shifts in home range during times of military activity, with some species actually leaving the area. Other work has shown that red-tailed hawks not previously exposed to Army UH-1 helicopter overflights showed a stronger avoidance response than those that had already been exposed; although no differences were found in nesting success. The Fort Benning species list includes the red-tailed hawk along with other buteos (high soaring hawks) - the red-shouldered hawk and the broad-winged hawk. The Fort Benning list also includes the northern harrier, which winters throughout the south. A study conducted in Mississippi on a U. S. Navy bombing range noted a harrier hunting throughout a bombing event. Between bombing runs the bird hunted over a larger area of the bombing range; however, during bombing the harrier seemed to focus more on the target area. It was deduced that the harrier was probably taking small mammals and birds flushed from cover by the bombing.
- Mammals: Some studies have shown that desert mule deer will habituate rapidly to jet aircraft noise. White-tailed deer at Fort Benning may be expected to similarly habituate to any disturbance, because they are generally known as a very adaptable species. Some work has shown that coyotes will change their daily activity in response to military training maneuvers.

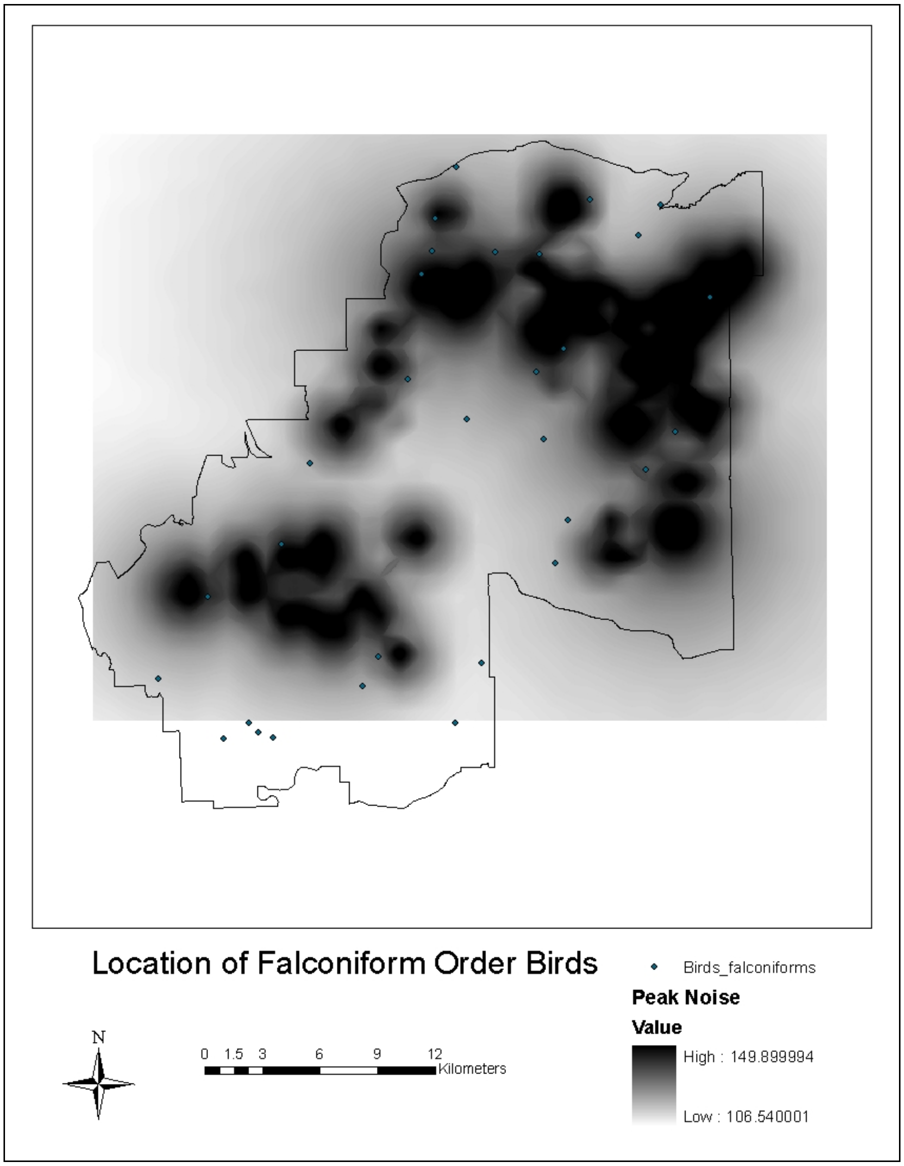


Figure 22. Falconiform order bird survey data overlaid on peak noise grids.

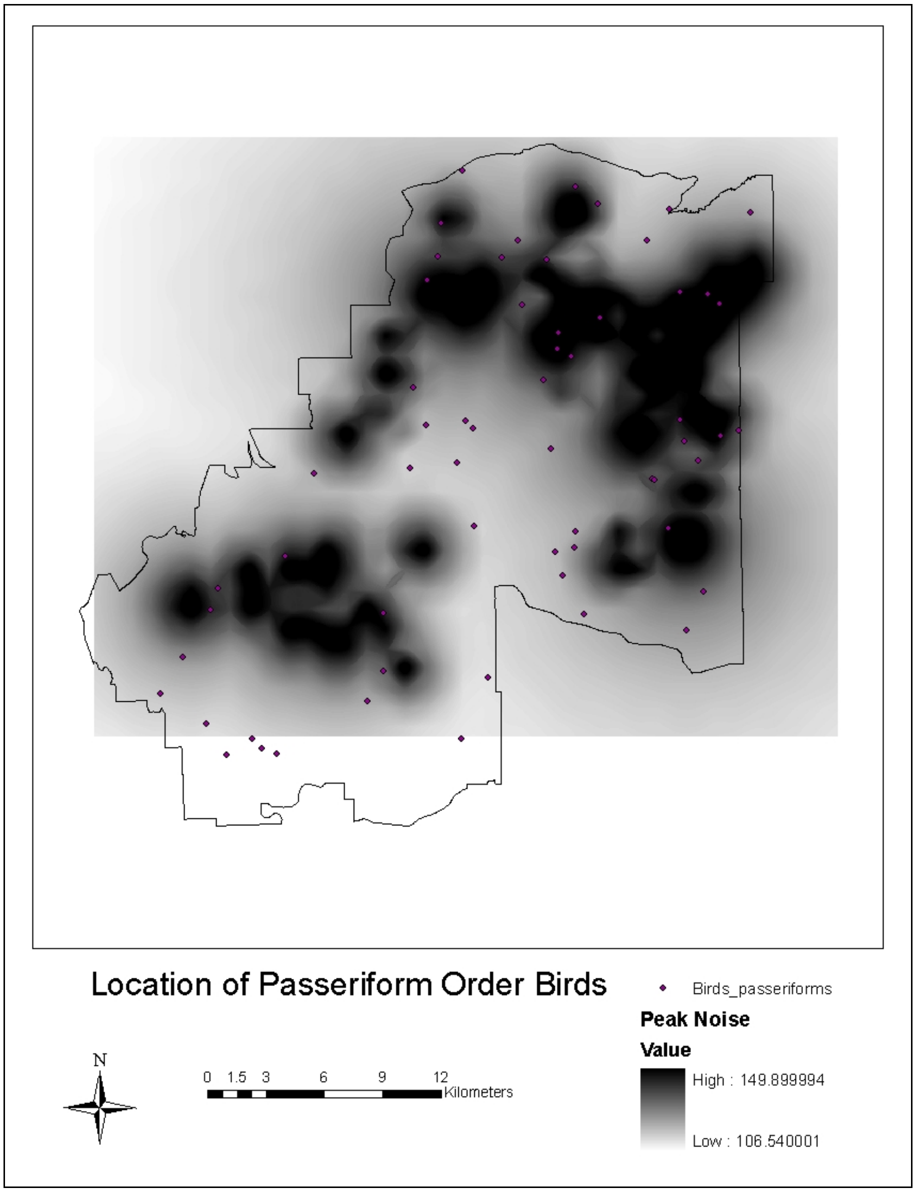


Figure 23. Passeriform order bird survey data overlaid on peak noise grids.

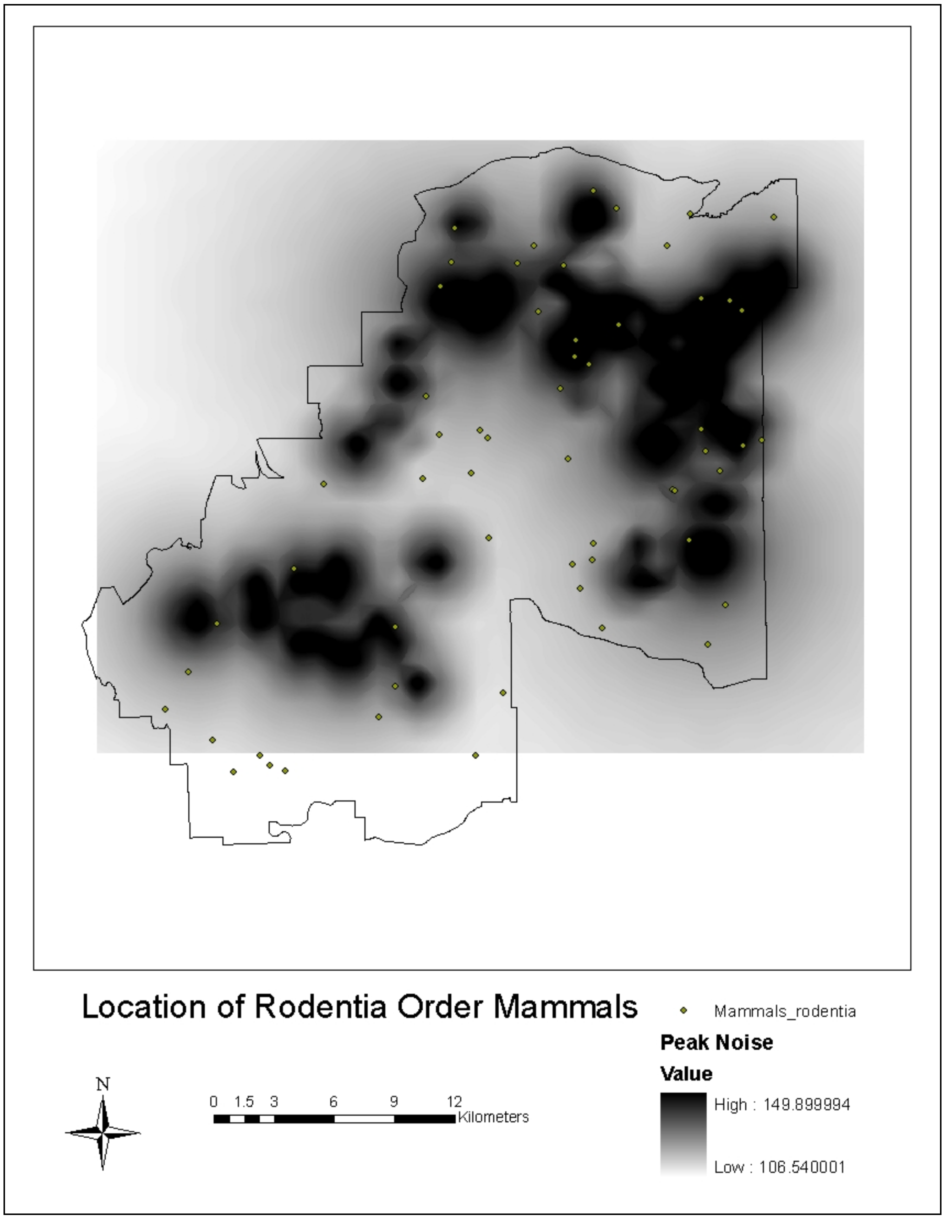


Figure 24. Rodentia order mammal survey data overlaid on peak noise grids.

On a general observation of the LCTA survey data over the noise grids, it was found that species occurrence was not affected by noise since there were sightings in high noise and low noise regions. However this result could be a function of the type of data which reports sightings and not nest/habitat locations. Data on nest/habitat locations and temporal status of the species in their nests/habitats would be a useful indicator to identify possible effects of noise on species.

- White Tailed Deer (Game species): Deer harvest records are available by training compartment for the year 2003-2004. A map of the deer harvest concentrations is presented in Figure 25. The white areas on the map represent zero deer harvested, generally because they overlap with ranges or other areas where hunting is not allowed and not because there are no deer there. The red areas are dud areas where hunting is also not allowed. However this data may be biased by how often and when the training compartments were open for hunting (Mark Thornton, Fort Benning, GA). Hence the deer harvest estimates may not be reliable estimates of deer population in Fort Benning.

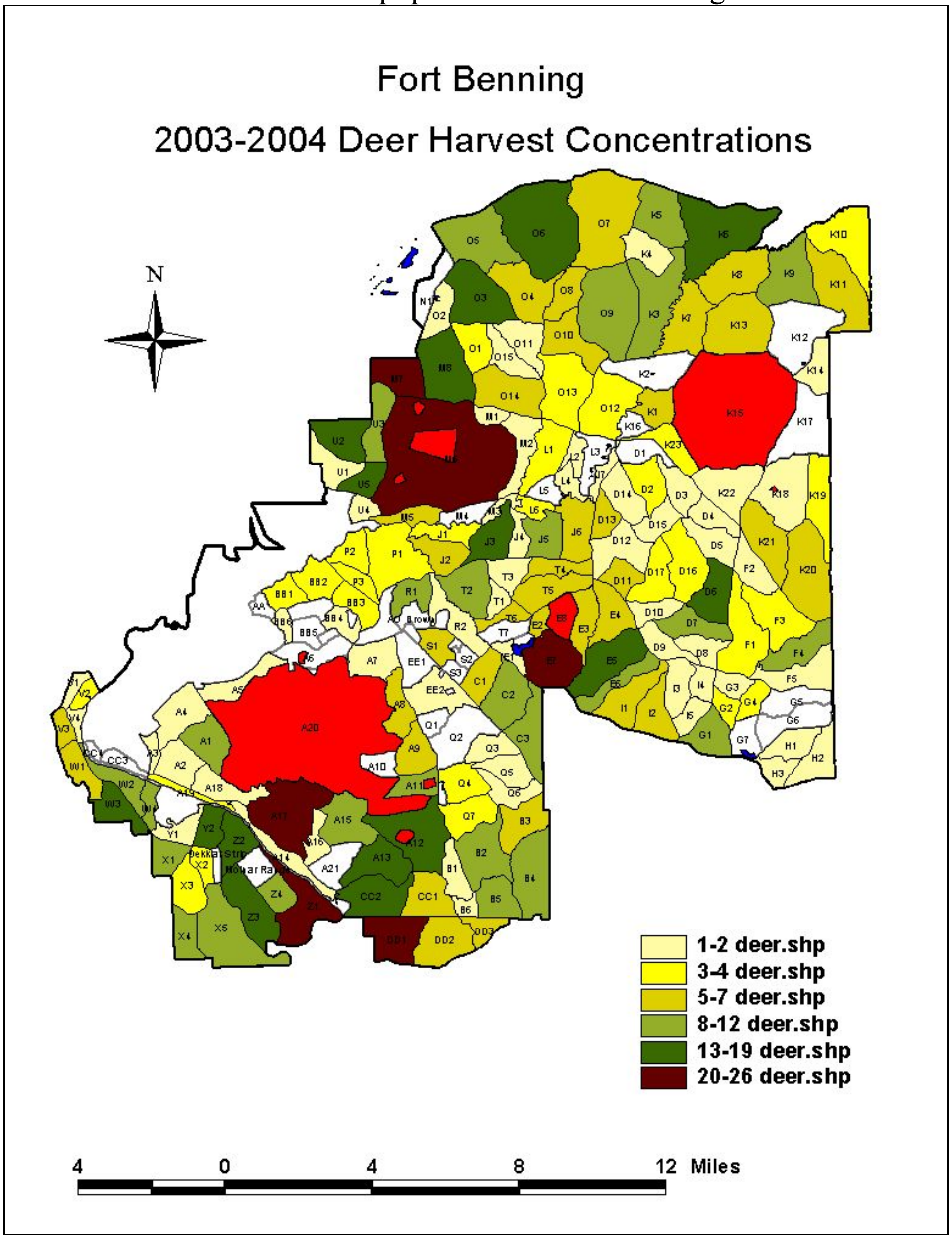


Figure 25. Deer harvest concentrations in Fort Benning by training area.

- Bobwhite Quail (Game species): Quail count survey data were obtained from Fort Benning. Figure 26 shows the routed on which the quails were surveyed on. The quail count data provides locations on these routes where quail whistles were heard in 2003, 2004 and 2005. Since this data is not comprehensive in Fort Benning, and since it did not contain information on habitat or nest locations, the data could not be used for analysis in RSim.

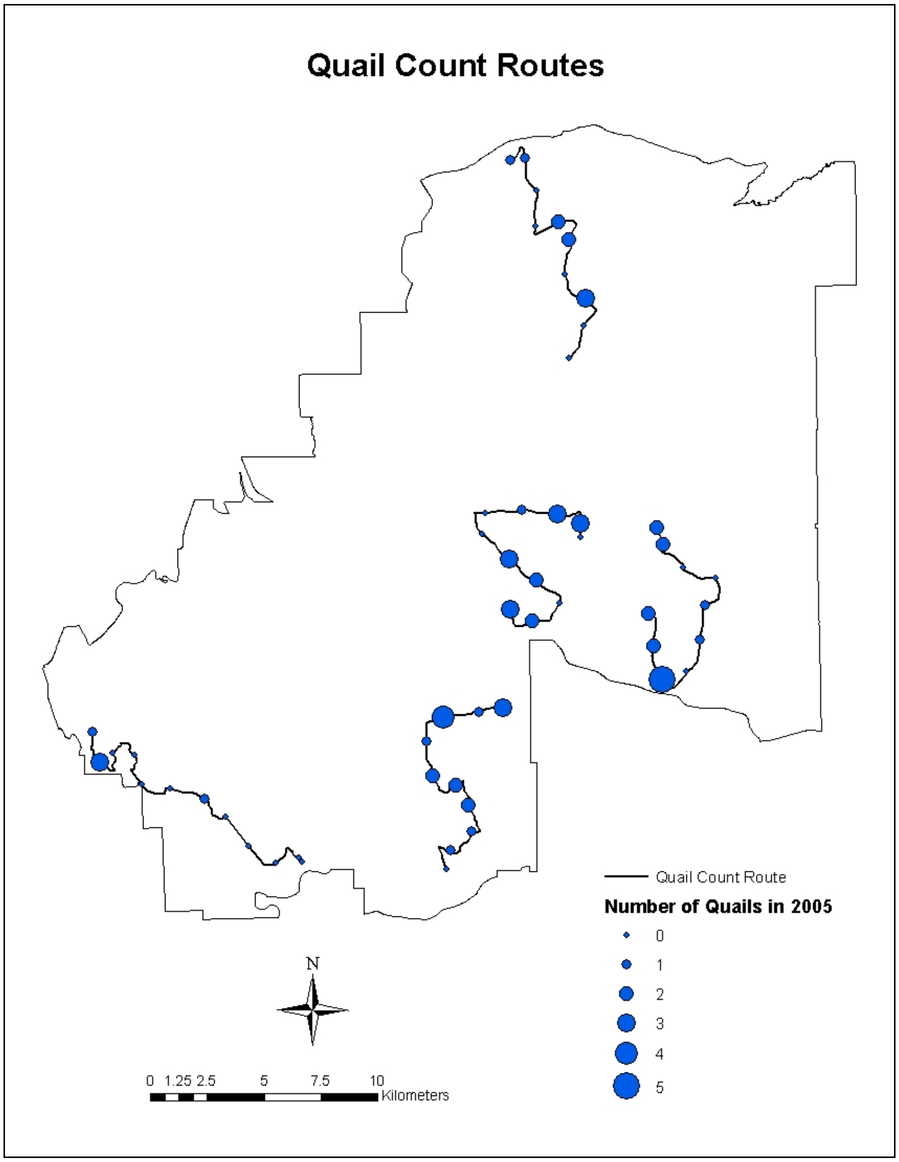


Figure 26. Quail count data in Fort Benning.

3.8.3 Discussion

The results of the survey data for groups of species were plotted on noise contour maps, and many of these locations are in high-blast-noise areas, but it is still unclear if animals were present during times of high blast noise. For this reason, we believe that nest or burrow locations would be more reliable indicators of effects from noise. Hence it was found that none of the data were suitable for RSim applications. This indicates the shortcomings of available data and the type of data required.

3.9 Development of Transition Rules For Non-Urban Land-Cover Classes

3.9.1 Introduction

The RSim model initially included urban growth rules. In order to incorporate the growth and changes that may happen in non-urban land-cover types, the land cover changes of the region was observed for past years. The land cover trend was determined by using change detection procedures in ArcGIS 9.0® that helped in identifying changes from one land-cover type to another. Changes to and from urban classes were not considered in the results since they were being dealt with using different growth rules. Based on the land cover changes happening over a period of time, the annual rate of change was calculated. These changes were incorporated in the form of a transition matrix from which the transition growth rules were derived.

Since forest management activities are different within Fort Benning and the surrounding private lands, the transition rules were calculated separately for Fort Benning and regions outside Fort Benning. Outside Fort Benning, National Land Cover Datasets (NLCD) of 1992 and 2001 were used. The 2001 data set covers only the northern part of the RSim study region. The data for the remaining regions is yet to be released. Hence currently, the changes observed in the northern portion are assumed to be representative of changes in all areas outside Fort Benning in the 5 County study region. Within Fort Benning, land-cover data sets from 2001 and 2003 were used to derive the transition rules.

This report describes the processes carried out for analyzing the change between two sets of land-cover data sets for the RSim study region (the counties of Chattahoochee, Harris, Marion, Muscogee and Talbot). Land cover data for the study region were available for 4 different time periods – 1992, 1998, 2001 and 2003 (Figures 27, 28, 29, and 30). Land-cover data for 1972, 1983/86, 1991, 2001 and 2003 were also available for Fort Benning. The results of the change detection carried out for the RSim region, regions outside Fort Benning and within Fort Benning are explained below.

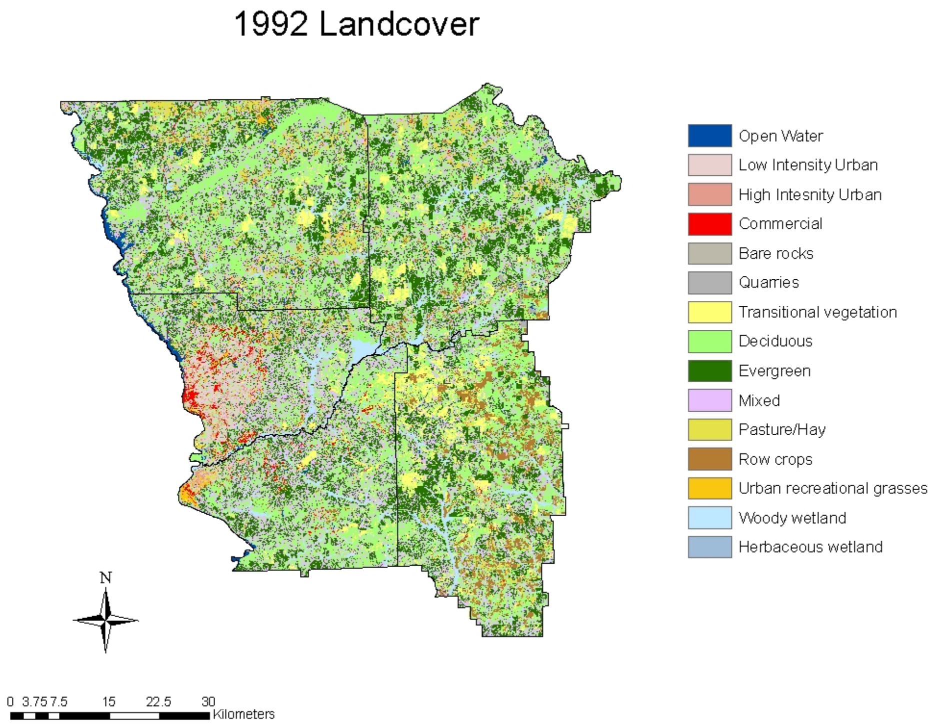


Figure 27. MRLC 1992 land cover.

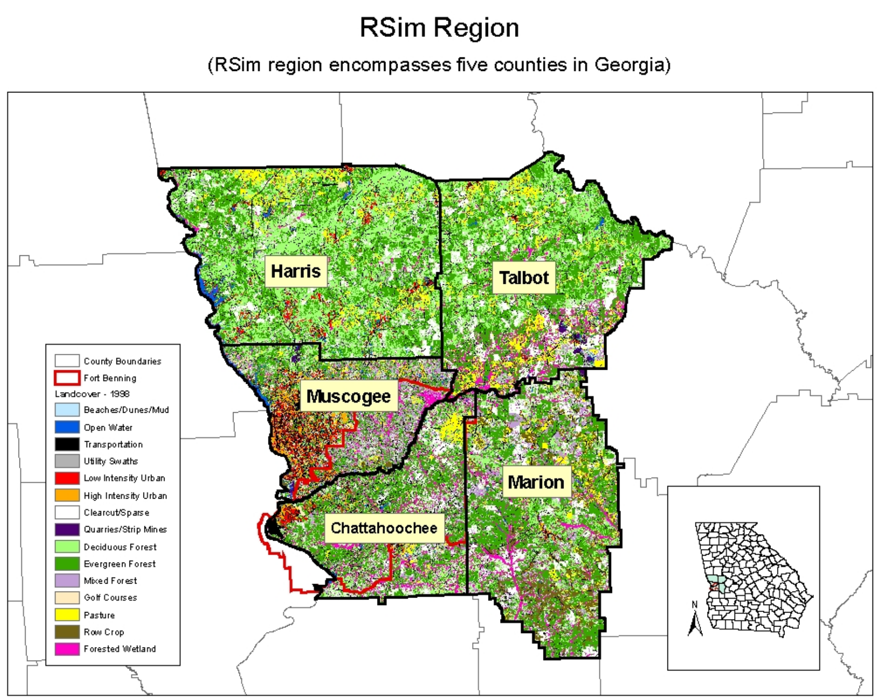


Figure 28. 1998 land cover (source: University of Georgia)

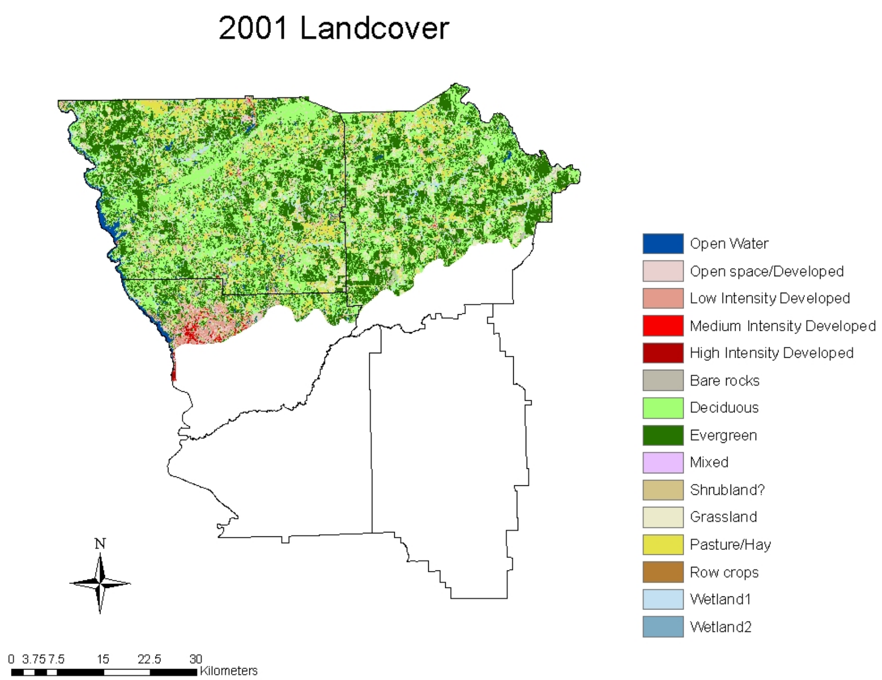


Figure 29. MRLC 2001 Land cover.

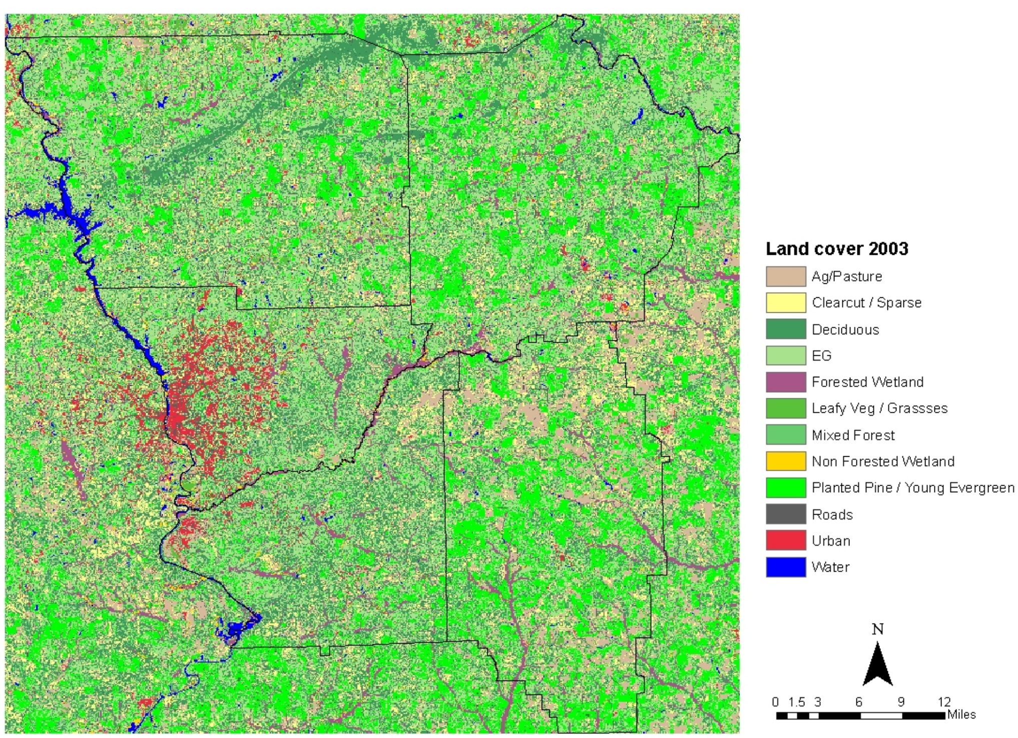


Figure 30. 2003 Land cover (source: Georgia Institute of Technology)

3.9.2 Change Detection between 1998 and 2003 Land-Cover Data

The first dataset, a 1998 land-cover map, was created by Natural Resources Spatial Analysis Laboratory (NARSAL), at the University of Georgia. The second dataset, a 2003 land-cover map was created by researchers at Georgia Institute of Technology and provided by Wade Harrison. This 2003 dataset has just been completed, and hence does not have detailed metadata to describe it. Discussions with Wade Harrison were useful in performing the change detection analysis for these data sets.

Some of the issues that had to be clarified before performing the change detection were:

1. Resolution. The 2003 land-cover data set has a resolution of 15 m whereas the 1998 data set has a 30 m resolution. For comparison, the 2003 data set was converted to a 30 m resolution.
2. Class definitions. The 1998 and 2003 land-cover maps were prepared by different organizations. Hence they followed different classification schemes. The 1998 land-cover dataset has 15 classes in the study region and the 2003 land-cover gas 12 classes. An attempt to compare classes is presented in Table 11. The 1998 land-cover classes 'Utility swaths', 'Beaches/dunes' and 'Mines/Quarries' are not directly comparable to any classes of the 2003 land cover. The distribution of those classes in the 2003 land cover is given in Table 12. They are not discussed in detail in the analysis.

Table 11. Mapping between classes of the two land-cover data sets.

1998 Land-cover category	2003 Land-cover category
Deciduous forest	Deciduous forest
Mixed forest	Mixed forest
Evergreen forest[d]	Planted pine/Young evergreen Evergreen
Clearcut/Sparse vegetation	Clearcut/Sparse
Row crop Pasture Golf courses	Ag/Pasture Leafy veg/Grasses[e]
Open water	Water Non-forested wetland[f]

[d] The 'Planted pine/Young evergreen' and 'Evergreen' classes of the 2003 land cover have been considered similar to the 'Evergreen forest' class of 1998.

[e] The 2003 land-cover data has an 'Ag/Pasture' class and a 'leafy vegetation/grasses' class that can be combined to represent agricultural land as a whole. The 'leafy veg/grasses' class is primarily comprised of winter grass areas. Anything with a lot of active chlorophyll that is not part of the planted pine class will show up in this class (personal communication with Wade Harrison). Hence it is being considered as part of the agricultural land class. Similarly in the 1998 data set, there are three separate classes – pasture, row crops and golf courses, which in general represent agricultural land. These three classes are comparable to the 'Ag/pasture' and 'Leafy veg/grasses' combined class which will be known as 'Ag land' in further discussion.

Low intensity urban High intensity urban	Urban[g]
Forested wetland	Forested Wetland
Transportation	Roads

Table 12. Percentage distribution of ‘Utility swaths’, ‘Beaches/Dunes’ and ‘Mines/Quarries’ land-cover areas in 1998 with respect to the 2003 land cover.

	2003 Land-cover class								
1998 Land cover class	*Decid uous*	*Mixed*	*Ever green*	*Clear cut/ sparse*	*Ag land*	*Water*	*Urban*	*Forested wetland*	*Roads*
Utility swaths	14.63	1.4	39.13	15.8	21.24	1.2	2.96	2.61	1.04
Mines/ Quarries	6.69	0.60	17.51	8.23	25.73	7.21	32.15	1.15	0.73
Beaches/ Dunes	10.30	0.81	22.49	4.61	1.63	28.73	1.36	29.81	0.27

3.9.3 Results of Change Detection

Using the nine classes listed in Table 11, the change detection analysis was carried out and the results are shown in Tables 13 and 14. The analysis was carried out in Arcview 3.1 using the spatial analyst extension. Maps indicating the areas of change and no change for each land-cover class are also included. The results of certain classes such as open water, urban areas and roads are not very useful and accurate and hence are not discussed in detail.

Deciduous – There has been a small decrease in the amount of deciduous forest between 1998 and 2003. However, when looking at the percent distribution of the 1998 land cover in 2003 (Table 14), it can be seen that only 29% of the area classified as deciduous forest in 1998 remained as deciduous forest. About 44% of the area was converted to evergreen classes. Such a change is not very likely to happen, and hence the results of this class analysis are not very reliable.

[f] There is no ‘non-forested wetland’ class in 1998. When the 2003 non-forested wetland area was analyzed with respect to the 1998 data, it was found that 35% of the non-forested wetland area in 2003 was water in 1998; 20% was forested wetland; 15% was deciduous forest; and 13% was evergreen forest. Since ‘open water’ of 1998 comprised most of the non-forested wetland, the ‘non-forested wetland’ class has been combined with the ‘water’ class of 2003, and it is comparable to the ‘open water’ class of 1998.

[g] The 1998 land-cover data has two urban classes – low intensity urban and high intensity urban. Since the 2003 land-cover has just one ‘urban’ class, the two 1998 land-cover classes have been combined to represent urban land.

Mixed forests – According to the change detection results, the amount of mixed forests reduced from 7.2% to about 1.6%. Further, 50% of the area classified as mixed forests in 1998 were classified as evergreen in 2003. The reliability of this class result is also questionable.

Evergreen – The percentage of evergreen forests increased from 32% in 1998 to about 49% in 2003. About 72% of the original area remained the same, and about 14% were converted to deciduous forests. This is a larger increase than expected. Some of the increase may be mixed forest in '98 reclassified as evergreen in '03 (Wade Harrison, TNC).

Clearcut/Sparse – There was a reduction in the clearcut/sparse areas from 10% to about 9%. According to Table 14, 50% of the clearcut area in 1998 is considered as evergreen in 2003 and only about 13% of the area remained as clearcut. From Table 15, it can be seen that most of the clearcut area in 2003 was deciduous and evergreen forests in 1998.

Ag land – There has been an increase in the agricultural land from about 8% to 9% in the RSim region. Results in table 15 suggest that a considerable part of this increase could be from clearcut regions, deciduous and evergreen forests. About 51% of the Ag land in 1998 remained the same in 2003.

Based on calculations from the data from the NASS Census of Agriculture (Table 16), there was a 13% increase in the land in farms between 1997 and 2002. This approximately matches the change observed in the land-cover maps. But when individual counties are considered, the change trend does not match between the land-cover maps and the agricultural census in most of the counties (refer to Table 16). Hence it is not clear if the results of the Ag land can be considered as accurate.

Forested wetland – According to the Table 13, there is a decrease in the percentage of forested wetlands from about 6.3% to 4.8%. Only 27% of the forested wetland in 1998 remained the same in 2003. Remaining areas were classified as deciduous or evergreen forests in 2003. Similarly from Table 15, it can be seen that a large portion of the land classified as forested wetland in 2003 was classified as deciduous, mixed or evergreen forest in 1998. Such results indicate a mix of class definitions during classification of the two land-cover data sets. This makes the results of the forested wetland class irrelevant.

Table 13. Change in percentage area of land-cover classes from 1998 to 2003.

Land cover class	% in 1998	% in 2003
Deciduous	24.06	19.91
Mixed forest	7.27	3.32
Evergreen	32.76	49.41
Clearcut/Sparse	10.11	8.26
Ag land	8.26	8.61
Water & non-forested wetland	1.56	1.83
Urban	2.77	1.87
Forested wetland	6.31	3.72
Roads	6.42	3.07

Table 14. Percentage distribution of 1998 land-cover classes in 2003.

	2003 LAND-COVER CLASS								
1998 LAND-COVER CLASS	*Deciduous*	*Mixed*	*Evergreen*	*Clearcut/ sparse*	*Ag land*	*Water & non-forested wetland*	*Urban*	*Forested wetland*	*Roads*
Deciduous forest	29.01	3.64	43.65	12.48	4.27	0.77	0.37	5.32	0.49
Mixed forest	25.59	1.37	50.43	10.15	5.55	0.38	0.87	4.89	0.78
Evergreen	13.94	0.88	72.12	5.01	3.44	0.69	0.45	2.81	0.66
Clearcut/sparse	18.11	1.22	50.60	13.35	11.19	0.44	1.53	2.22	1.33
Ag land	9.19	0.51	21.75	13.46	50.91	0.65	1.59	0.76	1.17
Open water	5.34	0.25	15.55	2.23	1.92	69.65	1.00	3.77	0.28
Urban	12.86	0.56	21.84	12.46	13.40	1.18	29.16	2.10	6.42
Forested wetland	28.74	2.44	31.85	4.81	1.61	3.48	0.21	26.56	0.29
Transportation	11.59	0.54	29.46	6.84	8.84	0.39	5.94	1.50	34.89

- No change

Table 15. 'From-To' matrix of land-cover conversions from 1998 to 2003.

	2003 LAND-COVER CLASS (TO) (Area in hectares)									
1998 LAND-COVER CLASS (FROM) ↓	*Deciduous*	*Mixed*	*Evergreen*	*Clearcut/ Sparse*	*Ag land*	*Water & non-forested wetland*	*Urban*	*Forested Wetland*	*Roads*	***Total area***
Deciduous forest	30876.12	3874.32	46458.63	13279.68	4541.85	821.25	397.35	5667.48	523.35	106440.03
Mixed forest	8225.46	441.54	16213.14	3263.67	1783.26	120.87	278.64	1571.76	250.11	32148.45
Evergreen forest	20195.37	1271.07	104502.69	7266.60	4988.07	998.01	649.62	4076.91	954.09	144902.43
Clearcut/Sparse	8103.42	545.58	22636.89	5972.04	5005.26	196.65	683.28	994.95	596.52	44734.59
Ag land	3305.97	184.41	7828.65	4844.16	18321.57	235.26	572.13	274.14	421.20	35987.49
Open water	368.37	17.46	1072.17	153.72	132.39	4801.5	69.12	259.56	19.26	6893.55
Urban	1575.09	68.76	2673.63	1526.04	1641.33	144.45	3570.48	257.67	786.51	12243.96
Forested wetland	8027.46	681.12	8896.59	1344.60	450.72	973.35	57.60	7420.23	81.45	27933.12
Transportation	3291.48	153.99	8367.21	1942.92	2510.64	110.34	1686.78	426.96	9908.46	28398.78
Total area	83968.74	7238.25	218649.60	39593.43	39375.09	8401.68	7965.00	20949.66	13540.95	**439682.4**

Table 16. Agricultural land-cover change comparison with change in land area of farms (from agricultural census data).

Region	**Area of land cover in agriculture (hectares)**		**Based on land cover**	**Land use based on census of Agriculture**
	1998	*2003*	*% change from 1998 to 2003*	*% change from 1997 to 2002*
Talbot	9025	7230	-24.84	15.85
Harris	7663	10160	24.58	23.58
Muscogee	3049	3304	7.71	28.98
Marion	14006	15306	8.49	-2.86
Chattahoochee	2240	4136	45.85	-18.09
RSim region	35984	40136	10.35	13.70

3.9.4 Aggregated land-cover change detection

The above results are not accurate and logical mainly because of the class differences between the two data sets. Further, since the classifications were carried out by different organizations, methodology differences and classification biases may affect the results. To negate some of the biases and class difference errors, the land cover classes were aggregated to more general classes and the changes between 1998 and 2003 land cover were tested. The following broad categories were created by combining classes:

Forest – The deciduous forests, evergreen forests, mixed forests and forested wetlands were combined to form one forest category in both the 1998 and 2003 datasets

Ag/Open – In the 1998 land cover, the row crops, pastures, golf courses, utility swaths and clearcut/sparse classes were combined to form the Ag/Open category. In the 2003 land cover, the ag/pasture, leafy veg/grasses and clearcut classes were combined.

Water – For the 2003 land cover, the non-forested wetland and the water classes were combined to form the broader water category. The open water class of 1998 was not combined with any other class.

Urban/Transportation – The low intensity urban, high intensity urban and transportation classes of 1998 were combined to create the urban /transportation category. In the 2003 land cover the urban and roads classes were combined.

The results of the change detection analysis using these classes are shown in Tables 17-19.

Table 17. Change in percentage area of land-cover classes from 1998 to 2003.

Land cover class	**% in 1998**	**% in 2003**
Forest	70.40	76.30
Ag/Open	18.65	16.82
Urban/Transportation	1.56	1.8
Water	9.19	4.88

Table 18. Percentage distribution of 1998 land-cover categories in 2003.

	2003 LAND-COVER CATEGORY			
1998 LAND-COVER CATEGORY	*Forest*	*Ag/Open*	*Urban/-Transportation*	*Water*
Forest	87.69	10.4	1.03	0.88
Ag/Open	55.01	41.68	2.86	0.45
Urban/Transportation	42.14	18.11	39.25	0.5
Water	27.46	3.69	1.28	67.57

Table 19. 'From-To' matrix of land-cover category conversions from 1998 to 2003.

	2003 LAND-COVER CATEGORIES (TO) (Area in hectares)				
1998 LAND-COVER CATEGORIES (FROM)	*Forest*	*Ag/Open*	*Urban/-transportation*	*Water*	***Total area***
Forest	273103	32382.81	3192.21	2745.99	311424.03
Ag/Open	45392.58	34389.09	2358.45	373.32	82513.44
Urban/transportation	17128.44	7360.2	15951.5	202.59	40642.74
Water	1892.97	254.16	88.38	4658.04	6893.55
Total area	337517	74386.26	21590.6	7979.94	**441473.76**

3.9.5 Use of Change Detection information in RSim

The information from the change detection analysis is to be used to estimate future changes in land cover for the deciduous forests, mixed forests, evergreen forests, clearcut/sparse regions and agricultural land. But it is not clear how reliable these comparisons are, largely because of the differences in the 1998 and 2003 classes. Aggregation of classes did not produce reasonable results. Hence these change detection results are unsuitable for generating non-urban land cover change rules for RSim.

3.9.5.1 Change Detection between 1992, 1998 and 2001 land-cover data

Land-cover data for the years 1992, 1998 and a 2001 (Figures 27, 28 and 29) were available. The 1992 dataset was created by the Multi-Resolution Land Characteristics (MRLC) Consortium. The 1998 land-cover map was created by Natural Resources Spatial Analysis Laboratory (NARSAL), at the University of Georgia. The third dataset, a 2001 land-cover map was also created by the MRLC consortium. However, only part of this data set is currently available. The data covering the northern portion of RSim has been completed. The data for the southern regions are yet to be released. Hence change detection using the 2001 data set was carried out only for the northern RSim region.

Change detection was carried out between each of the years 1992 and 2001, 1998 and 2001 and 1992 and 1998. The results are shown in Tables 20-23.

Table 20. Change detection results from 1992 to 2001.

Percentage distribution of 1992 land-cover classes in 2001								
	2001 LAND COVER							
1992 LAND COVER	***Water***	***Developed***	***Barren***	***Deciduous***	***Evergreen***	***Mixed***	***Herb veg***	***Wetland***
Water	**84.918**	1.562	0.263	6.776	2.476	0.197	1.647	2.160
Developed	2.083	**78.623**	0.636	4.304	7.117	0.365	6.576	0.296
Barren	0.302	4.455	**1.397**	11.386	68.795	0.578	12.389	0.698
Deciduous	0.802	5.405	0.348	**60.949**	15.802	0.542	11.643	4.509
Evergreen	0.355	4.655	2.033	11.263	**62.014**	0.591	18.704	0.385
Mixed	0.496	7.333	0.692	36.724	37.439	**1.150**	13.988	2.179
Herb veg	0.322	13.460	0.283	6.570	10.419	0.254	**68.532**	0.160
Wetland	2.093	1.287	0.449	33.865	13.671	1.181	8.647	**38.808**

Table 21. Change detection results from 1992 to 1998.

Percentage distribution of 1992 land-cover classes in 1998								
	1998 LAND COVER							
1992 LAND COVER	***Water***	***Developed***	***Barren***	***Deciduous***	***Evergreen***	***Mixed***	***Herb veg***	***Wetland***
Water	**73.542**	2.662	0.723	5.428	10.413	0.607	0.767	5.859
Developed	3.223	**65.140**	5.348	6.728	12.629	2.708	3.594	0.630
Barren	0.419	9.892	**13.518**	26.854	35.289	7.868	5.213	0.947
Deciduous	0.861	6.601	6.919	**56.504**	19.152	3.058	3.607	3.299
Evergreen	0.409	6.122	13.148	13.944	**61.030**	2.796	1.941	0.610
Mixed	0.679	8.197	8.635	34.132	38.345	**4.713**	3.484	1.815
Herb veg	0.715	15.128	11.150	10.898	8.085	1.528	**52.143**	0.353
Wetland	2.078	2.076	6.388	41.821	19.880	2.895	0.783	**24.081**

Table 22. Change detection results from 1998 to 2001.

Percentage distribution of 1998 land-cover classes in 2001								
	2001 LAND COVER							
1998 LAND COVER	***Water***	***Developed***	***Barren***	***Deciduous***	***Evergreen***	***Mixed***	***Herb veg***	***Wetland***
Water	**66.092**	3.964	0.461	12.827	8.260	0.276	6.069	2.051
Developed	0.857	**39.237**	0.840	16.433	24.414	0.461	16.969	0.790
Barren	0.394	5.913	**0.911**	23.612	20.018	0.436	47.746	0.970
Deciduous	0.512	3.139	0.444	**59.096**	20.739	0.874	10.230	4.965
Evergreen	0.881	4.810	1.516	21.767	**58.887**	0.630	9.986	1.522
Mixed	0.698	8.037	0.696	33.261	42.969	**1.047**	11.254	2.037
Herb veg	0.543	8.067	0.357	13.512	12.146	0.413	**64.510**	0.452
Wetland	5.010	1.951	0.592	40.555	15.376	1.094	7.750	**27.672**

Table 23. Percentage of land-cover classes in 1992, 1998 and 2001.

Percentage of Land cover			
	1992	**1998**	**2001**
Water	1.79	2.05	2.13
Developed	2.06	8.63	7.55
Barren	4.14	9.27	0.89
Deciduous	34.26	33.99	34.29
Evergreen	24.56	33.58	33.60
Mixed	23.62	3.42	0.68
Herb veg	7.14	6.58	17.67
Wetland	2.43	2.48	3.18

Based on the class definitions for data of each year, it was decided that the change from 1992 to 2001 was most appropriate and suitable. The change detection results from 1992 to 2001 were used to develop a list of probabilities of change for one land-cover class to change to another class in one year (annual change) (Table 24).

Table 24. Annual rates of change outside Fort Benning.

Annual Changes (percentage) outside Fort Benning - based on data from 1992 to 2001							
	Deciduous	***Evergreen***	***Mixed***	***Clearcut***	***Pasture***	***Row crops***	***Forested wetland***
Deciduous		1.76	0.06	0.76	0.53	0.00	0.50
Evergreen	1.25		0.07	1.59	0.48	0.01	0.04
Mixed	4.08	4.16		1.03	0.52	0.00	0.24
Clearcut	1.28	7.78	0.07		0.73	0.00	0.08
Pastures	0.69	1.04	0.03	0.39		0.02	0.02
Row crops	0.82	1.39	0.02	0.97	5.64		0.02
Forested wetland	3.79	1.52	0.13	0.74	0.20	0.00	

Assumptions made while deriving the non-urban growth rules are:

- There are no changes in the following categories –

- Open water
- Beaches
- Utility swaths
- Quarries/Strip mines
- Golf courses

- The changes in the following categories are taken care of in other growth rules
  - Low intensity Urban
  - High intensity Urban
  - Transportation
- For changes outside Fort Benning, the transitions are derived from the northern part of RSim region only (since the 2001 land cover is available for that region only)
- Changes within Fort Benning were derived separately using different data sets available for the Fort Benning region.

3.9.5.2 Change Detection within Fort Benning

The 2001 and 2003 land cover data of Fort Benning were created by U. S. Army Engineer Research and Development Center (ERDC), Fort Benning. The 1974, 1983/86 and 1991 classifications were created by Lisa Olsen, Oak Ridge National Laboratory from the North American Landscape Characterization (NALC) triplicate data (Olsen et al., 2007). The change detection results carried out among these datasets are presented in Tables 25 to 27.

Table 25. Change detection results within Fort Benning from 2001 to 2003.

Fort Benning: Percentage distribution of 2001 land-cover classes in 2003										
	Water	***EG/-Planted***	***EG***	***Decid***	***Shrub***	***Herbaceous***	***Bare ground***	***Mixed***	***Roads***	***Urban***
Water	**71.92**	0.36	13.40	7.83	4.10	0.31	0.41	1.40	0.13	0.11
EG/Planted	0.00	**59.43**	20.03	4.21	9.42	2.61	0.00	4.30	0.00	0.00
EG[1]	0.05	9.13	**54.23**	8.84	2.39	1.42	0.16	23.61	0.12	0.05
Decid	0.10	1.24	12.36	**47.46**	2.04	0.46	0.05	36.19	0.07	0.03
Shrub	0.06	0.15	2.81	70.86	**14.09**	1.76	0.12	10.12	0.03	0.00
Herbaceous	0.12	0.06	1.89	19.76	44.09	**26.68**	3.69	3.05	0.39	0.27
Bare ground	0.06	0.09	1.16	5.46	10.34	35.57	**43.22**	1.25	0.58	2.28
Mixed	0.05	0.37	20.01	37.60	2.94	1.18	0.14	**37.57**	0.10	0.04
Roads	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**100.00**	0.00
Urban	0.26	0.17	4.14	4.63	9.49	4.51	6.52	2.43	4.90	**62.91**

[1] EG = Evergreen forest

Table 26. Change detection results within Fort Benning from 1974 to 1983/86.

Fort Benning: Percentage distribution of 1974 land cover in 1983/86						
	Urban	*Clearcut*	*Deciduous*	*Mixed*	*Evergreen*	*Water*
Urban	**44.69**	43.46	1.41	8.05	2.27	0.12
Clearcut	13.15	**47.72**	5.34	24.18	9.31	0.29
Deciduous	0.84	8.06	**38.96**	29.21	22.85	0.07
Mixed	1.52	12.91	21.96	**34.02**	29.44	0.14
Evergreen	1.14	5.79	13.96	32.76	**46.06**	0.30
Water	0.00	0.00	0.00	0.00	0.00	**100.00**

Table 27. Change detection results within Fort Benning from 1983/86 to 1991.

Fort Benning: Percentage distribution of 1983/86 land cover in 1991						
	Urban	*Clearcut*	*Deciduous*	*Mixed*	*Evergreen*	*Water*
Urban	**45.99**	44.20	2.12	4.50	1.38	1.81
Clearcut	8.14	**60.97**	6.10	18.81	5.73	0.25
Deciduous	0.32	2.91	**58.48**	17.83	20.40	0.06
Mixed	1.05	15.15	22.01	**28.71**	32.62	0.46
Evergreen	0.80	6.49	17.29	25.64	**49.55**	0.23
Water	4.11	7.91	2.80	8.65	5.55	**70.98**

Fort Benning is a public land which is under routine forest management. Since there are moves to increase the longleaf pine habitats, management using fires is a common practice. Under such a scenario, it will be expected that the mixed forests and deciduous forests become evergreen in the course of a few years with fire management.

Analyzing the results of the change detections and based on the above premise, it was found that the change from 2001 to 2003 was most appropriate to derive non-urban growth rules. The annual rates of change within Fort Benning from the 2001 to 2003 change detection results are presented in Table 28.

Table 28. Annual rates of change within Fort Benning.

Annual Changes (percentage) - based on changes from 2001 to 2003							
	EG/Planted	*EG*	*Decid*	*Shrub*	*Herbaceous*	*Bare ground*	*Mixed*
EG/Planted	**29.72**	10.02	2.10	4.71	1.30	0.00	2.15
EG	4.56	**27.12**	4.42	1.20	0.71	0.08	11.81
Decid	0.62	6.18	**23.73**	1.02	0.23	0.02	18.10
Shrub	0.08	1.40	35.43	**7.04**	0.88	0.06	5.06
Herbaceous	0.03	0.95	9.88	22.04	**13.34**	1.85	1.52
Bare ground	0.05	0.58	2.73	5.17	17.78	**21.61**	0.62
Mixed	0.18	10.01	18.80	1.47	0.59	0.07	**18.78**

3.10 Risk Approach

The risk assessment component of RSim was developed to present expected ecological effects of noise, air quality, total nitrogen in water, and habitat disturbance (from prescribed burns, wildfires, training, roads and/or logging). Background levels of these stressors are considered, as well as levels associated with future, hypothetical scenarios. Potentially susceptible and valued ecological receptors of concern include (1) fish or invertebrate communities (N in water), (2) forest communities (urbanization, ozone, wildfires), (3) red-cockaded woodpecker (RCW, *Picoides borealis*) population (noise and/or habitat disturbance) and (4) gopher tortoise (*Gopherus polyphemus*) population (noise and/or habitat disturbance). Continuous exposure-response models are probably not available for any combinations of these stressors and receptors. Therefore, effects models are primarily thresholds, and exceedances of these thresholds are displayed in RSim.

Examples of risk outputs in RSim include

- Map of RCW clusters where woodpeckers may temporarily flush from nests because of noise
- Map of gopher tortoise burrows where animals are potentially immobilized because of blast noise
- Map of habitat areas with burrows that gopher tortoises may potentially abandon because of predicted tree cover changes
- Area of otherwise suitable habitat for gopher tortoise that is unsuitable because of small patch size
- General stability of installation population of RCW, based on number of territories (compared to effects threshold)
- Map of streams where amphibian growth or development may be impaired (if we have estimates of nitrate concentrations)
- Map of areas around roads that are likely to have low abundances of particular songbirds
- Probability that the abundance of a random bird population is reduced, based on distance from the nearest road
- Map of vegetation with potentially injured foliage due to ozone exposure
- Map of vegetation predicted to have at least a 20% reduced yield due to ozone exposure

We made advances in four principal risk assessment areas: (1) compilation of thresholds for effects of noise and vegetation change on red-cockaded woodpecker and gopher tortoise, (2) compilation of thresholds for effects of nitrate in surface water on amphibians, (3) compilation of thresholds for vertebrate disturbance by roads, (4) review of EPA report that summarizes threshold concentrations for ozone on vegetation, and (5) developing a framework for transboundary risk assessments at military installations and on a habitat model for gopher tortoise. The risk assessment framework is justified because of the species, stressors, and management goals that cross installation boundaries. Our risk assessment framework paper (Efroymson et al. 2006) focuses on the problem formulation or planning phase. Components of the framework include: (1) regional management goals such as installation Integrated Natural Resources Management Plans and land acquisition, (2) involvement of multiple stressors, and (3) large-scale assessment endpoint entities. Challenges of selecting measures of exposure include: quantifying exposure to aggregate stressors, describing land cover consistently in the region, describing rates of land-cover transition, scaling local measurements to a region, and aggregating or isolating exposures from within and outside of the installation. Measures of effect that are important to transboundary or regional ecological risk assessments at military installations are those that represent: effects at a distance from the stressor, large-scale effects, effects of habitat change or fragmentation, spatial extrapolations of localized effects, and integrated effects of multiple stressors. These factors are reflected in conceptual models. The transboundary approach is described in the paper by Efroymson et al. (2005).

Our habitat model for gopher tortoise was developed for a five-county region in Georgia based our analysis of documented locations of gopher tortoise burrows at Fort Benning (Baskaran et al. 2006). Using burrow associations with land cover, soil, topography and water observed at Fort Benning, potential gopher tortoise habitats were analyzed with binary logistic regression. We generated a probability map for the occurrence of gopher tortoise burrows in the five-county region surrounding Fort Benning. An accuracy assessment was performed for select locations outside Fort Benning.

3.11 Scenarios in RSim

3.11.1. Urban growth scenario

Our methods for simulating population growth generated new urban pixels in land-cover maps for the five-county region around Fort Benning. Urban growth rules are applied at each iteration of RSim to create new urban land cover. The subsequent RSim modeling step then operates off a new map of land cover for the five-county region. The computer code (written in Java) has been built from the spontaneous, spread center, and edge growth rules of the urban growth model from Sleuth (Clarke et al. 1996, Clarke and Gaydos 1998, Candau 2002, Gigalopolis model website: http://www.ncgia.ucsb.edu/projects/gig/index.html).

The urban growth submodel in RSim includes both spontaneous growth of new urban areas and patch growth (growth of preexisting urban patches). We have focused first on generating low-intensity urban areas (e.g., single-family residential areas, schools, city parks, cemeteries, playing fields, and campus-like institutions). Three sources of growth of low-intensity urban pixels are modeled: spontaneous growth, new spreading center growth, and edge growth. First, an exclusion layer is referenced to determine those pixels not suitable for urbanization. The exclusion layer includes transportation routes, open water, the Fort Benning base itself, state parks, and a large private recreational resort (Callaway Gardens). Spontaneous growth is initiated by the selection of *n* pixels at random, where *n* is a predetermined coefficient. These cells will be urbanized if they do not fall within any areas defined by the exclusion layer. New spreading center growth occurs by selecting a random number of the pixels chosen by spontaneous growth and urbanizing any two neighboring pixels. Edge-growth pixels arise from a random number of non-urban pixels with at least three urbanized neighboring pixels.

Low-intensity urban pixels become high-intensity urban cells according to different rules for two types of desired high-intensity urban cells:

- central business districts, commercial facilities, high impervious surface areas (e.g., parking lots) of institutional facilities that are created within existing areas with a concentration of low-intensity urban cells; and
- industrial facilities and commercial facilities (malls) that are created at the edge of the existing clumped areas of mostly low-intensity urban cells or along four-lane roads.

For the first high-intensity category, land-cover changes occur in a manner similar to changes in low-intensity growth, as described above: a spontaneous growth algorithm converts random low-intensity pixels to high-intensity pixels, and an edge growth algorithm converts random low-intensity urban pixels with high-intensity urban neighbors to high-intensity pixels. The second type of conversion from low-intensity to high-intensity urban land use is road-influenced growth and is described in the next section.

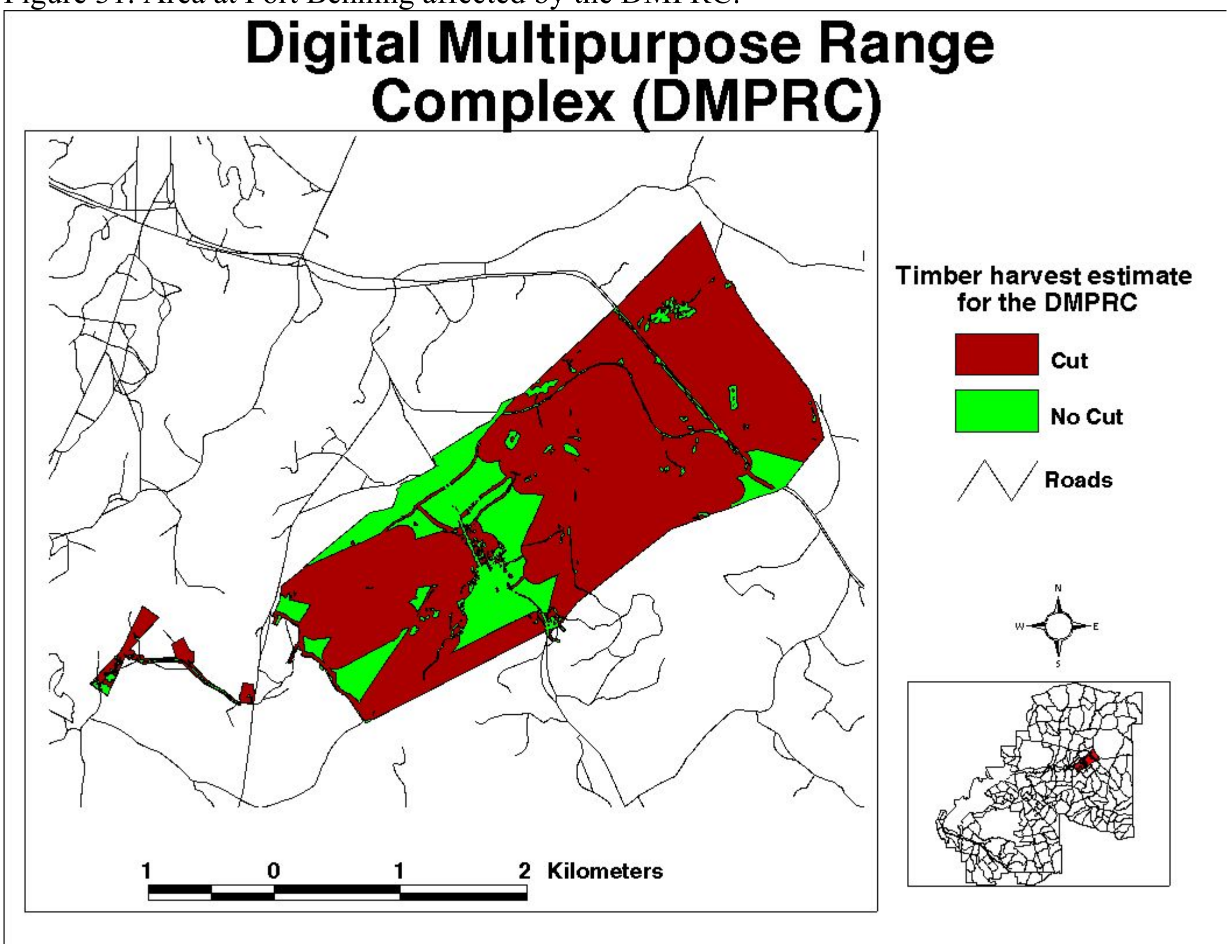
3.11.2. Military training scenario in RSim– the Digital Multi Purpose Range Complex (DMPRC)

Fort Benning is in the process of constructing a Digital Multi Purpose Range Complex (DMPRC) to provide a state-of-the-art range facility, in order to meet the Installation's training needs for conducting advanced gunnery exercises in a realistic training environment. The DMPRC construction will be incorporated within the RSim model and the impact of this training range on air, water, noise and habitat of species will be estimated.

As of now, the data for the regions where trees are cut for the DMPRC has been obtained and added in the RSim model. About 1500 acres of the region will be cleared of trees, shrubs and other vegetation. This clearing work started in October 2004.

Figure 31 indicates the DMPRC site with cut and no cut regions. The 'cut' category refers to vegetation that is being cleared. The 'no cut' category refers to regions that are not cleared.

Figure 31. Area at Fort Benning affected by the DMPRC.



3.11.3. New road scenario

The road-influenced urbanization submodel of RSim consists of growth in areas near existing and new roads by considering the proximity of major roads to newly urbanized areas. The new-road scenario makes use of the Governor's Road Improvement Program (GRIP) data layers (as described above) for new roads in the region. Upon each iteration (time step) of RSim, some number of non-urban pixels in a land-use land-cover map are tested for suitability for urbanization according to spontaneous and patch growth constraints. For each pixel that is converted to urban land cover, an additional test is performed to determine whether a primary road is within a predefined distance from the newly urbanized pixel. This step is accomplished by searching successive concentric rings around the urbanized pixel until either a primary road pixel is found or the coefficient for a road search distance is exceeded. If a road is not encountered, the attempt is aborted.

Assuming the search produces a candidate road, a search is performed to seek out other potential pixels for urbanization. Beginning from the candidate road pixel, the search algorithm attempts to move a "walker" along the road in a randomly selected direction. If the chosen direction does not lead to another road pixel, the algorithm continues searching around the current pixel until another road pixel is found, aborting upon failure. Once a suitable direction has been chosen, the walker is advanced one pixel and the direction selection process is repeated.

In an effort to reduce the possibility of producing a road trip that doubles back in the opposite direction, the algorithm attempts at each step of the trip to continue moving the walker in the same direction in which it arrived. In the event that such a direction leads to a non-road pixel, the algorithm's search pattern fans out clockwise and counterclockwise until a suitable direction has been found, aborting upon failure. Additionally, a list of road pixels already visited on the current trip is maintained, and the walker is not allowed to revisit these pixels.

The road trip process continues until it must be aborted due to the lack of a suitable direction or the distance traveled exceeds a predefined travel limit coefficient. The latter case is considered a successful road trip. To simulate the different costs of traveling along smaller two-lane roads and larger four-lane roads, each single-pixel advancement on a two-lane road contributes more toward the travel limit, allowing for longer trips to be taken along four-lane roads such as the GRIP highways.

Upon the successful completion of a road trip, the algorithm tests the immediate neighbors of the final road pixel visited for potential urbanization. If a non-urban candidate pixel for urbanization is found, it is changed to a low-intensity urban type, and its immediate neighbors are also tested to find two more urban candidates. If successful, this process will create a new urban center that may result in spreading growth as determined by the edge growth constraint.

Roads also influence the conversion of low-intensity urban land cover to high-intensity urban land cover. For the second high-intensity urban subcategory (industry and malls), the RSim code selects new potential high-intensity-urbanized cells with a probability defined by a breed coefficient for each cell. Then, if a four-lane or wider road is found within a given maximal radius (5 km, which determines the road_gravity_coefficient) of the selected cell, the cells adjacent to the discovered four-lane or wider road cell are examined. If suitable, one adjacent cell is chosen for high-intensity urbanization. Hence, the new industry or mall can be located on the highway, within 5 km of an already high-intensity urbanized pixel

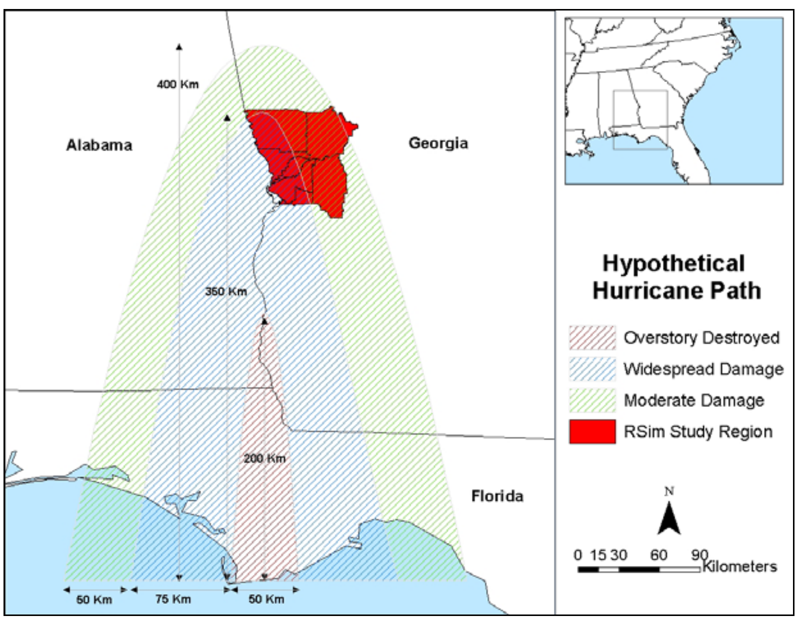
3.11.4. Hurricane Scenario for RSim

Hypothetical hurricanes with direct north hits, in a westerly and easterly path with respect to the study region, are to be simulated in RSim (Figure 32). The extent and depth of hurricane path from the coast is modeled to be similar to that of Hurricane Hugo on the South Carolina coast (Conner, 1998). Three zones of damage are identified after the hurricane:

- Overstory destroyed – 100% of the forest land cover are destroyed and converted to clearcut/sparse land cover.
- Widespread damage - 50% of the forest land cover are destroyed and converted to clearcut/sparse land cover.
- Moderate damage - 25% of the forest land cover are destroyed and converted to clearcut/sparse land cover.

10 years after the hurricane damage, the original forest land cover is restored by increments of 10% restoration (or re-growth) every year. It is assumed that only the forest land covers change after the hurricanes.

Figure 32.Modeled hurricane path in RSim.



4. Results and Accomplishments

4.1 Results and Analysis from Sample Runs of RSim

4.1.1 Land cover

Based on the conditions and scenarios selected (see Appendix), the projected changes in land cover are depicted in Figure 33. Graphs of the changes in land cover for the two scenarios are in Figures 34 and 35. The business as usual (BAU) case results in a slight increase in the area of land under high intensity urban (from 4,329 ha to 4,662 ha) and a greater increase in land under low intensity urban cover (from 7914 ha to 10053 ha). Clear-cut land declines sharply from 44,735 ha to 20,317 ha, and row crops decrease from 11,101 ha to 4,876 ha. Pasture lands increase from 22,886 ha to 27,147 ha.

The high urban growth scenario results in a different pattern of changes in urban lands and agricultural lands than in the BAU case (compare Figures 34A and 34B). The high growth case results in a great increase in the area of land under both high intensity urban (from 4,329 ha to 115,789 ha) and low intensity urban cover (from 7,914 ha to 135,247 ha). Clear-cut land declines from 44,735 ha to 10,963 ha, and row crops decrease from 13,101 ha to 1,837 ha. Contrary to the BAU case, for the high urban growth scenario, pasture lands decline from 22,886 ha to 7,779 ha.

Forest cover also changes in the BAU scenario (Figure 35A). Both mixed forest and forested wetlands decline from 32,145 ha to 12,775 ha and from 27,933 ha to 14,310 ha, respectively. Deciduous forest and evergreen forests both increase in area from 106,439 ha to 118,880 ha and from 144,905 ha to 191,419 ha, respectively.

Compared to the BAU case, forest cover has a quite different pattern of change over the next 40 years for the high urban growth scenario (compare Figures 35A and 35B). In the latter case all the common forest categories decline with mixed forest changing from 32,145 ha to 10,765 ha, forested wetlands from 27,933 ha to 10,561 ha, deciduous forest from 106,439 ha to 42,488 ha, and evergreen forests from 144,905 ha to 70,911 ha.

4.1.2 Water quality

For the BAU scenario, the water quality module predicts that the watershed containing the city of Columbus [Hydrological Unit Code (HUC) 30104] exhibits the greatest changes in N and P exports as compared to the high urban growth scenario, which predicts that the watershed northeast of Columbus (HUC 21206) has the greatest changes in these exports. The overall change in N export for the RSim region was 1,002,406 kg and 1,609,560 kg, respectively for the BAU and high urban growth scenarios. The overall change in P export was 164,703 kg and 374,600 kg, respectively for the BAU and high growth scenarios.

Figure 33. Map of RSim projected land cover at end of RSim projection time period

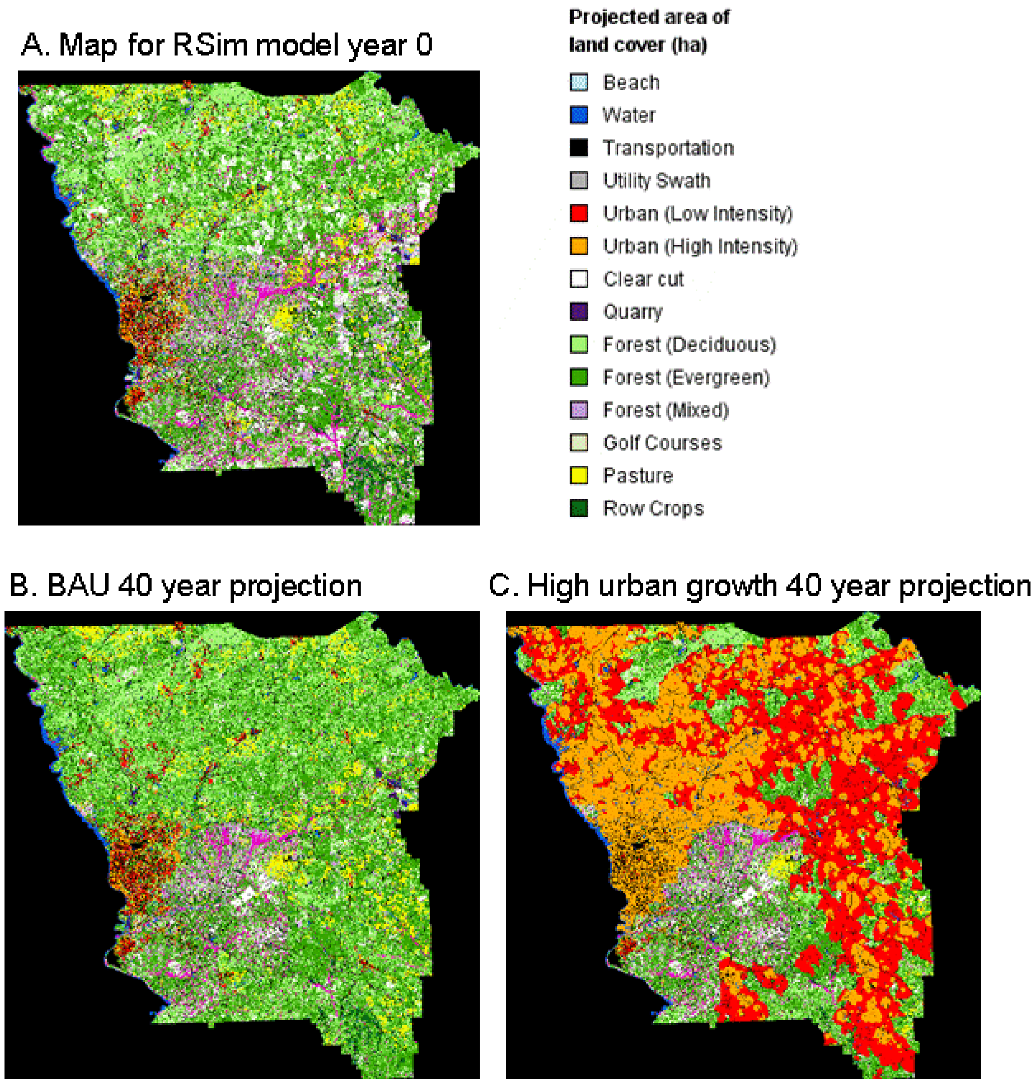
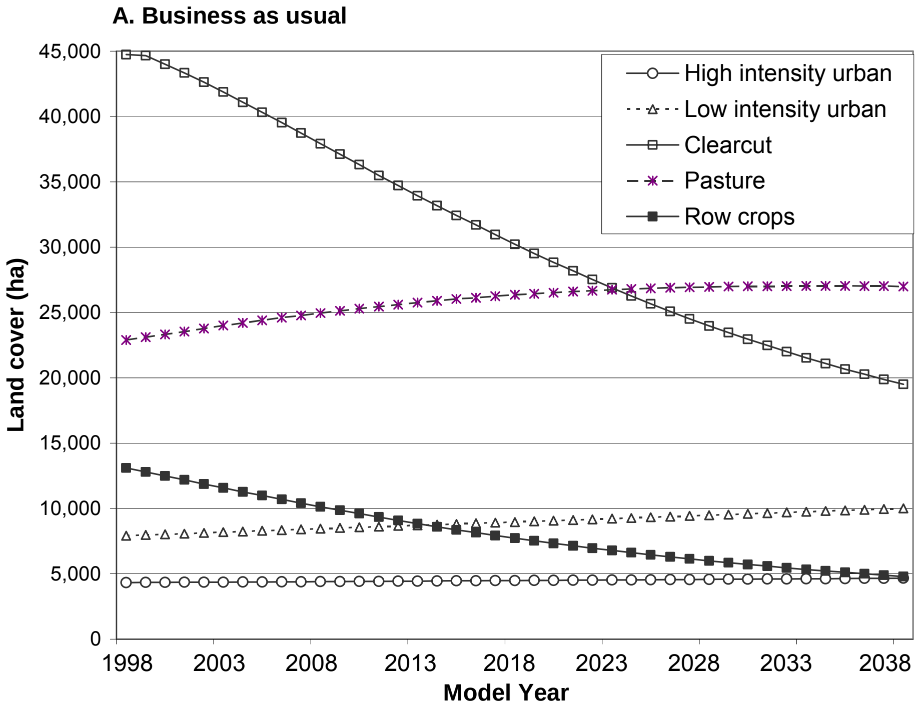


Figure 34. Graph of changes in urban land cover, pasture and row crops over the 40 year RSim projection for the (A) business as usual (BAU) scenario and (B) the high urban growth scenario.



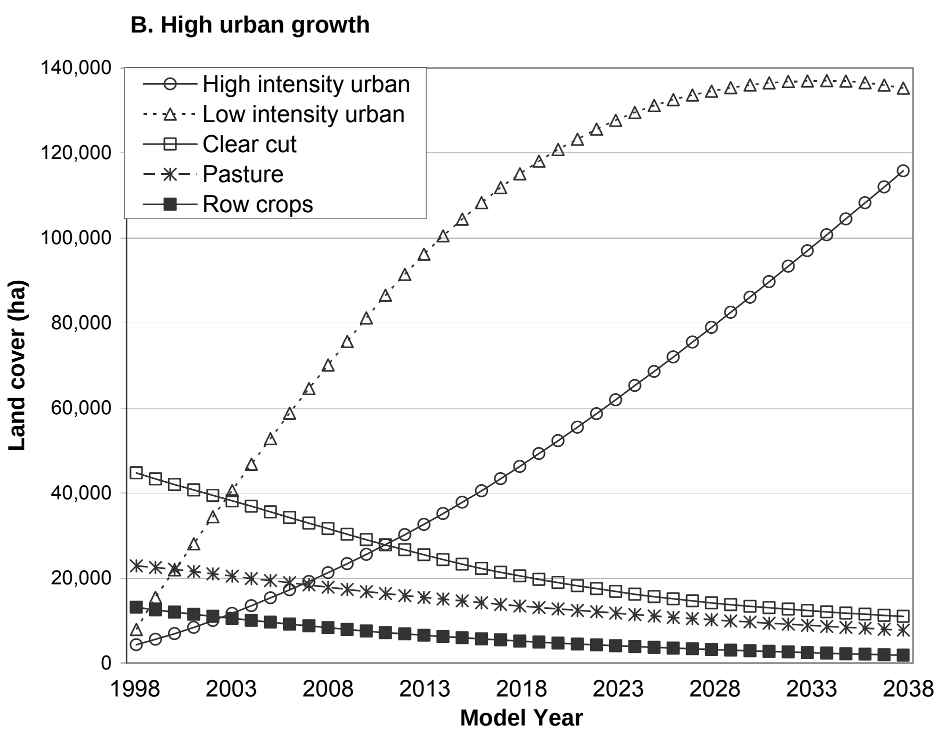
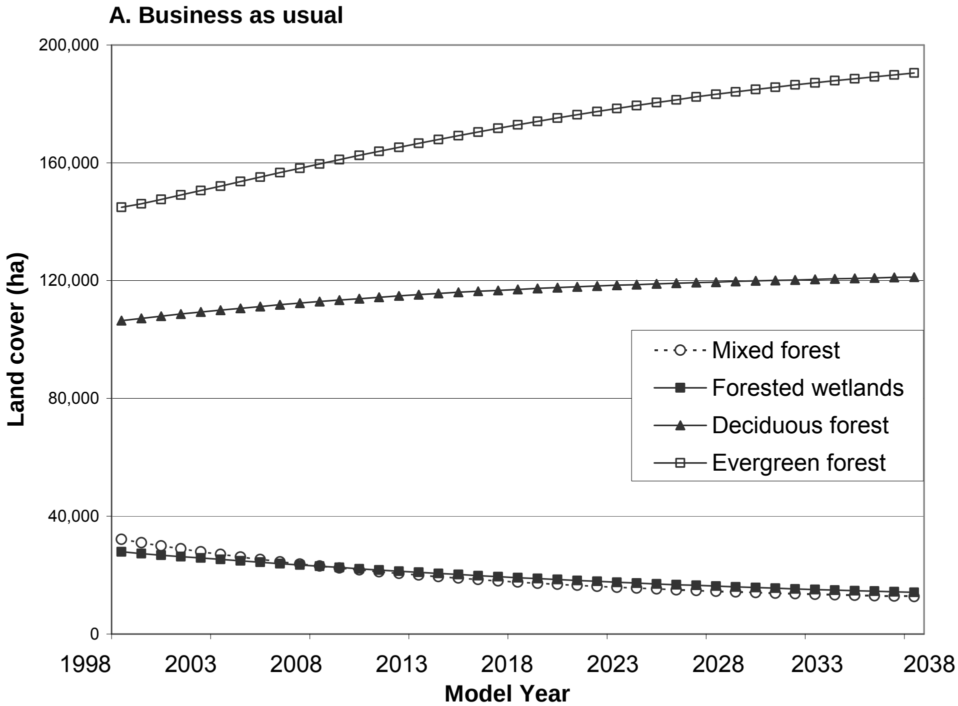
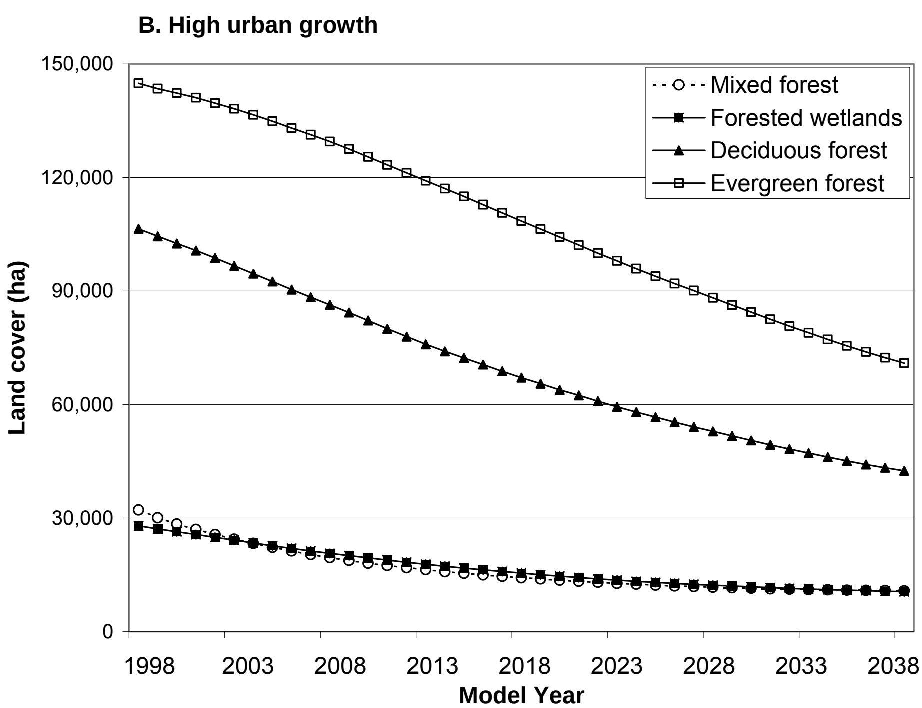


Figure 35. Graph of changes in forest cover over the 40 year RSim projection for the (A) business as usual (BAU) scenario and (B) the high urban growth scenario.





4.1.3 Air quality

For both the BAU and high urban-growth scenarios and meteorological episode selected, the air quality module predicts that area-wide peak 8-hour average ozone concentrations will change from 71 ppbv (parts per billion by volume) in 1998 to about 90 ppbv in 2038. For the 40-year simulation, the concentration of ozone exceeds the secondary standard for 34 years of the projection period. Thus, ozone exceeded the level protective of crops and other vegetation for 85% of the future time in both cases.

4.1.4 Habitats of key species in the region

4.1.4.1 Red-cockaded woodpecker

For both the BAU and high urban growth scenarios, RSim projects that by model year 2038, 150% of the original clusters of red-cockaded woodpecker will exist in the five-county region. Most of these clusters will be located in evergreen forest within the boundaries of Fort Benning that mature to the stage in which they can support red-cockaded woodpecker by the end of the 40-year model run. This quantity of new active breeding clusters would meet the U.S. Fish and Wildlife Service's (USFWS) goal of 361 active clusters for Fort Benning (Beaty et al. 2003)).

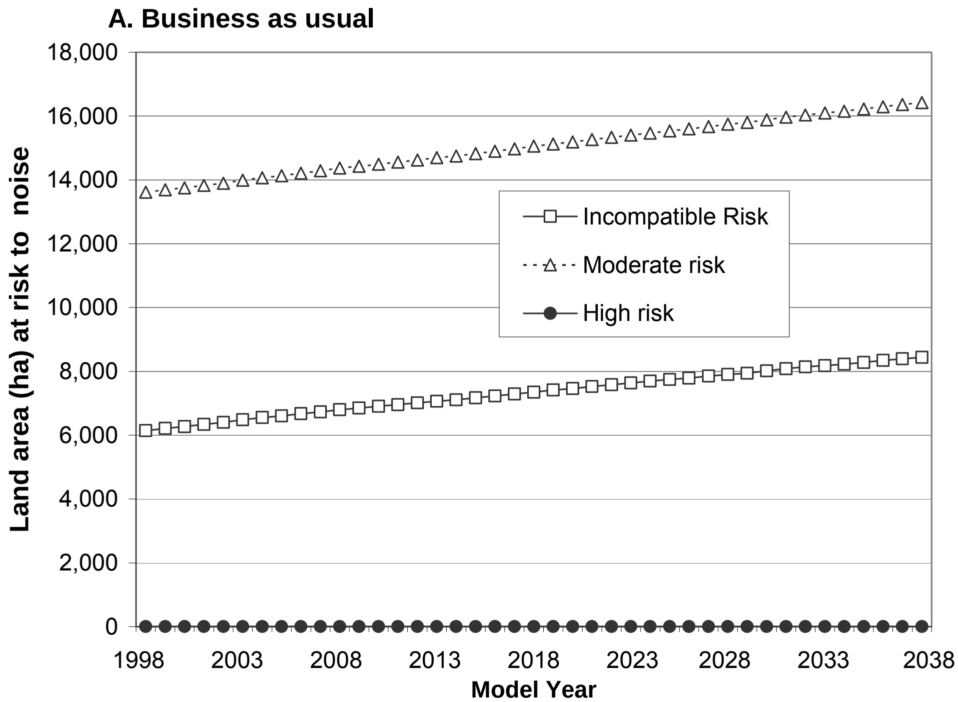
4.1.4.2 Gopher tortoise

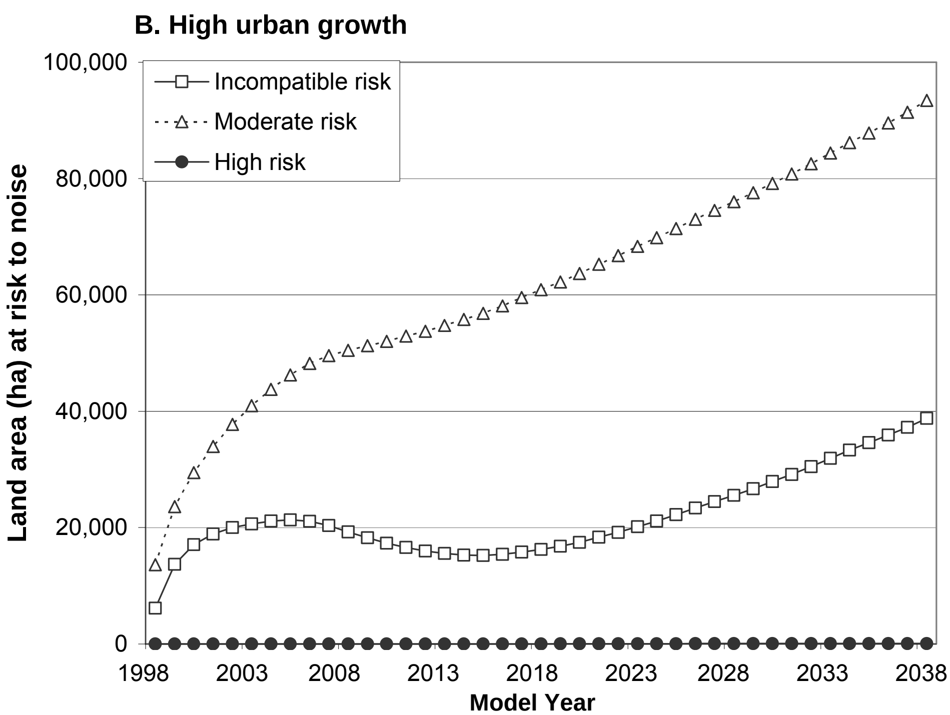
RSim projects that by model year 2038 there will be 181,288 ha and 113,639 ha of potential area of suitable gopher tortoise habitat, respectively, for the BAU and growth scenarios. These projections compare to 190,918 ha of gopher tortoise habitat in the five-county region at the beginning of the simulation. The 5% and 40% reduction in potential area that can support gopher tortoise burrows reflects changes in land cover, respectively, for the BAU and high urban growth scenarios. The probability of having suitable gopher tortoise habitat increases when more land cover is in pasture, clear-cuts, forest, transportation corridors, row crop, or utility swaths.

4.1.4.3 Noise

For the two scenarios, the land-cover changes combine to produce different patterns of risk from noise (compare Figures 36A and 36B). There is a moderate risk of noise complaints from areas outside Fort Benning of 6,334 ha and 93,448 ha area, respectively, for the BAU and high urban growth scenarios. The areas likely to experience a high risk of noise complaints are relatively small in both scenarios, with 9 ha and 61 ha being likely by 2038 for the BAU and growth scenarios, respectively. RSim predicts that by 2038 that 8,335 ha and 38,773 ha, respectively, of land outside of Fort Benning will be in land uses that are incompatible with noise produced from military activities in the simulated scenarios.

Figure 36. Land area at moderate or high risk to noise complaints and having incompatible land uses for projected noise risks for the (A) business as usual (BAU) scenario and (B) the high urban growth scenario over the 40 year RSim projection period.





4.2 Discussion of RSim Results

Projected changes in land cover under the two scenarios are quite different (Figures 34 and 35). The BAU case has only small changes in the urban land cover types. A sharp decline in clear-cut land and a more gradual decline in row crops occur as pasture and urban land covers increase in area. At the same time, evergreen and deciduous forest land increases in the region. In contrast, the sharp increase in high intensity urban lands under the high urban growth scenario is associated with a decline in all of the other land cover types mentioned above. These alterations in land cover types set the stage for changes in some of the other environmental conditions discussed below.

Changes in N and P export to streams over the 40 year projection are dramatic for both scenarios. For the BAU case, the watershed containing the city of Columbus has more N and P export after 40 years than any other watershed in the region because it continues to be the center of high urban intensity. The city is currently the largest in the five-county area and in 1998 had the greatest concentration of urban land cover in the region. The high proportion of urban lands in Columbus increases the paved areas, which allow runoff as well as industrial inputs of N and P into the water system. Over the 40 year projection no land-cover changes in the rural or forested landscape are great enough to overcome the large influence of Columbus on the water quality of the region. These results suggest that current and future attention to the effects of N and P export should concentrate on the city of Columbus under the BAU case. However, under the high growth scenario, the intense urban development shifts to the northeast of Columbus, i.e., to HUC 21206. This difference in results for the two scenarios suggests that the region needs to be prepared to support infrastructure needs and increases in N and P export for a larger region than just the Columbus area.

Under both scenarios, air quality changes projected from land-cover changes in the five county region are similar. There are two principal ways that forest cover can affect air quality, and both are represented in RSim. First, forests emit reactive hydrocarbons that are involved in the chemistry that forms ground-level ozone. In the southeastern United States, biogenic hydrocarbons are ubiquitous, and stoichiometrically speaking, the region is saturated with hydrocarbons. Removing sources of hydrocarbons under any conceivable scenario (or adding more for that matter) has no significant effect on ozone concentrations. For this reason, projected changes in the forest cover have a negligible effect on hydrocarbon emissions and thus ozone concentrations. The second way that forests can affect ground-level ozone is via emissions of nitrous oxide (NOx) either due to burning activities in the forest or from activities associated with logging or otherwise managing or using the forest (e.g., chainsaws, trucks, and all terrain vehicles). Estimates of all these contributions are included in RSim's current emissions inventory. However, forest-related emissions are only a small part of the total emissions inventory, and they may or may not have any impact on the "peak" ozone concentration in the region (which is what RSim calculates and the variable that is generally related to human health and vegetation growth). Further, if the changes in the forest emissions are not co-located with the place where the peak ozone concentration occurs (which is likely since the peak pollutant concentrations tend to occur more near the urban areas where the more intense emissions sources are located), there is unlikely to be an effect on the NOx calculation from forest changes. Lastly, forest emissions are distributed over a large area so the effect is diluted at any one location. Even though all of these factors are included in the air quality module of RSim, there is little effect on regional air quality due to land-cover changes. This result was rather surprising for the region.

The habitats for the two species included in RSim respond in quite different ways to projected changes in land cover from the BAU and growth scenarios. The number of clusters of red-cockaded woodpecker has few differences in the two scenarios because the clusters are almost all located in military lands that are not subject to urban expansion. In contrast, the habitat of gopher tortoise is strongly affected by the increased urban growth scenario, for that case instigates a change in several land-cover types that are suitable for gopher tortoise. Under the BAU case, the clear-cut lands undergo a steady decline from 44,735 ha to 20,317 ha; whereas in the growth scenarios these clear-cut lands decline to about 10,963 ha. At the same time, pasture lands are projected to increase from about 22,890 ha to 27,150 ha in the BAU scenario and decline to 7,800 ha in the high growth scenario. The decline in both clear-cut and pasture lands that results from the high urban growth reduces the area suitable for gopher tortoise habitat.

The projected risk from noise under the two scenarios is very different (Figure 36). The BAU case is associated with a slight increase in the lands with moderate risk from noise and incompatible land use. In contrast, the high level of urban growth projects dramatic increases in the area of land with moderate risk from noise and incompatible land use. Both of these scenarios display a local peak in risk from noise that occurs just before model year 2008 [when the area of land in high and low intensity urban categories are approaching similar values (Figure 34)]. Before 2008, both urban types contribute to the noise risks, but the declining area of residential home lands after 2008 causes the noise risk to also decline for a short period until the influence of the rising high intensity urban land causes another rise in the noise risk. The location of these new urban lands near the boundary of Fort Benning (Figure 33) and within the range of noise impacts is another factor affecting the sharp rise in risk from noise.

This regional, cross-sectorial analysis of environmental influences of land-use change in west, central Georgia illustrates some of the benefits of using such a holistic approach to land-use planning. A broader understanding of potential effects of land-use changes can be achieved. This information can be used to streamline management activities by allowing potential effects to be considered before a decision is made and it promotes discussion and planning for on-the ground repercussions of decision making. In addition, the simulation model identifies conditions under which cross-sectorial effects should be considered (or not considered). For example, in the scenarios presented here, impacts on air quality are negligible. At least in the absence of large changes in dominant emissions factors such as might be associated with increases in industrial and transportation use or in technology changes, the effects of land-use change on air quality are small. Use of the RSim model enhances understanding of interactions between environmental effects (feedbacks and cumulative impacts) and therefore allows for greater understanding of the conditions necessary to sustain several environmental amenities of the region.

4.3 Coordination with Outside Experts

A formal review of RSim was held on March 16, 2006. A presentation of the model was followed by a live demonstration. Questions and discussion occurred throughout the review, and reviewers were asked to complete an evaluation form.

The reviewers felt that the March version of RSim adequately fulfilled its claim to be able to integrate land-use changes with air quality, water quality, noise and habitat of select species. They anticipated that the final version of RSim (to be completed in the summer of 2006) will do this well. The reviewers were interested in seeing cumulative impacts or other ways to represent the sensitivity of one factor versus others for each output layer.

The reviewers recognize that some modules are further developed than others and that some modules will ultimately be more or less flexible than others. Noise, in particular, is a rather static parameter. They suggested following through on implementation of a burning and forest growth module.

The reviewers thought that the user interface appropriately conveys the information used to project changes and what those changes might be. They suggest that training may be required for uses to learn about the model.

The reviewers thought that RSim will serve as a useful tool for managers to improve their ability to make decisions about resource use and management. One reviewer pointed out that the potential of RSim to be successful now depends upon successful technical transfer and user support.

The reviewers thought that the water quality module in RSim captures changes that might occur over the landscape. This is the most developed module in RSim, and it is very flexible and spatially distributed.

They felt that the air quality module in RSim adequately captures changes that might occur over the landscape. They thought the module was quite detailed and reflects a lot of underlying atmospheric science and chemistry. They appreciated the clever use of off-line intensive model as input to this model.

The reviewers recognized that the noise module in RSim is static and thought that this approach may be totally appropriate for the questions being asked at an annual time step.

The reviewers thought that the red-cockaded woodpecker habitat module and the gopher tortoise burrow model seemed to be a good relationship to experimental studies. They suggested that we add the ability to project habitat for trillium even though it is not likely to be as impacted by increased training.

The main suggestion for improving RSim was further development of the user interface. They urged that the next phase of RSim involve input from users (or potential users).

The reviewers identified the key strengths of the RSim approach to be:

a. It gets planners thinking about ecology in more specific terms during comprehensive planning; highly dynamic and responsive to alternative points of view; great for collaborative discussion.'
b. The resolution is incredible

c. It is focused on reasonable number of variables keyed to mission needs and avoids the temptation to develop a universal tool.

4.4 Complementarity between RSim and the mLEAM models

4.4.1 Introduction

This part of the final report discusses the complementarity between the RSim model and the mLEAM models developed under SERDP project SI-1257 and describes how the two research products can best fit together in a toolkit for Department of Defense land managers. The section on complementarity was developed by members of both teams of researchers from SI- 1259 and SI-1257. The report also includes a discussion on how receptive RSim is to different data formats, the degree to which model algorithms have been validated, and what future modeling components may be important to add (for example, the impact of prescribed burns and wildfires on regional air quality).

This report begins with an overview of each of the models as well as a short description of the U.S. Army's Fort Future, for it may serve as a vehicle for integration. A comparison of end-user delivery approaches of the models is also included, for it points out some of the needs for integration. The report concludes with a section on RSim's data formats, validation and future needs.

4.4.2 Complementarity between the RSim model and the mLEAM models

<u>4.4.2.1. Overview of LEAM</u>

LEAM is short for "Land use Evolution and Impact Assessment Modeling". It is a synthesis of approach and software that allows a regional planning stakeholder community to explore the long-term (20-40) year consequences of proposed regional plans. The LEAM approach has been successfully applied to regions containing Peoria, Illinois; East St. Louis and St. Louis, Missouri; Traverse City, Michigan; and now the Chicago Metropolitan Area extending across Wisconsin, Illinois, and Indiana. It has also been tested with the Fort Benning and Scott Air Force Base (located in central Illinois) communities. Generally speaking, the LEAM approach proceeds as follows:

1. A quick generation of urban growth is completed using nationally available data.
2. Results are presented at a regional planning charrette which then poses the following questions to participants:
    - What is right and what is wrong with the projections?
    - What local data and information is available to replace the national data?
    - What are the perceived encroachment problems/challenges?
    - What are the local drivers to growth?
    - What regional planning ideas should be tested?
3. The LEAM urban growth model is modified, including changes to the source code, to capture the needs identified in the charrette. A 9 or 20 sector economic model is used to project future economic and population growth based on proposed major changes in employment (e.g. installation mission changes).
4. The model is calibrated – often with historic census data.

5. Revised model outputs are reviewed by the stakeholder community until they are satisfied with the base model projections.
6. Regional planning proposals are tested with the model.
7. As needed/requested, future urban patterns are input into various models such as:
    - Transportation models
    - Habitat fragmentation models
    - Economic impact models
    - Utility (e.g. water, electric grid, and sewer) models
8. Results are captured in a report for general public consumption and presented at regional stakeholder meetings.
9. The new localized LEAM model often becomes part of the regular tools of the community to test further regional planning suggestions.

Each full application of LEAM results in an urban growth model specially created to address the specific needs of the target communities. Step 1, above, is accomplished with a generic version of LEAM's land use change model. This software is written in the "C" language and, like RSim, owes its beginnings to the SLEUTH model. It is 30-meter grid-cell based, uses a 1-year time step, and generates future urban patterns across a region based on calculated dynamic attractiveness of undeveloped areas to new urban residential, commercial, and open-space. Raw GIS maps are processed with in-house ESRI GIS scripts to create the needed input files for the LEAM land use change model. Results of the model are further processed with ESRI-GIS for reporting and image production purposes.

LEAM applications are tailored to meet the specific needs of target communities and rely heavily on intensive interactions with multiple stakeholders across a region.

<u>4.4.2.2 Overview of mLEAM</u>

While LEAM provides a powerful approach designed to specifically address the regional planning challenges facing a community composed of many stakeholders, mLEAM provides a very inexpensive and quick, though generic, approach to project residential growth around military installations and forecast the implication of that growth on future military training and testing opportunities. mLEAM analyses begin with a GIS technician downloading free and nationally available data such as land cover (NLCD), elevation (DEM), roads/highways, and state/federal lands. These are processed to generate raster and vector maps in a common UTM projection and common area extending through a defined set of counties. These maps are then loaded with scripts into the Linux/Unix based GRASS GIS and automatically processed. There are three primary steps.

1. LEAMram is the residential attractiveness model that generates a residential attractiveness map based on the combined attractiveness of each 30-meter square area with respect to distances to roads, highways, interstates, intersections, employment, other residential, trees, and water. The attractiveness is measured through an analysis of the current pattern of residential areas across the study area.
2. LEAMluc is a version of the LEAM land use change model. Only residential development is generated, however, because the primary incompatible land use challenge involves military activities and residential.

3. LEAMtom is the training opportunities module, which runs a number of new GIS analyses that predicts the probability of complaints from residential neighbors in response to military generated noise, dust, and smoke. Night sky illumination due to city lights is also synthesized.

Each of these steps generates results not only within the GRASS GIS, but automatically to a web site for immediate end-user viewing. Posted results include text, map images, urban growth movies, and GIS maps for downloading into a user's local GIS software.

4.4.2.3 Overview of Fort Future - LEAM

Fort Future is a U.S. Army Corps of Engineer's funded research and development program that provides a framework for providing Web-browser based simulation modeling tools that allow installation planners to simulate the consequences of on-installation construction on utility systems, to test the impact of utility failures (e.g. from terrorist attacks), to design new buildings and new sites for buildings, and to run LEAM models. The Fort Future LEAM (FF-LEAM) prototype is expected to be running for demonstration purposes in the Fall of 2006. The interface is expected to allow a user to open a standard browser to access the Fort Future web toolbox site. For FF-LEAM, the user will be provided with a map of the United States showing counties. After zooming to an area of interest, the user will select a coterminous set of counties and request automated mLEAM runs. After validating the request as reasonable (e.g. not too big), the system will schedule simulation runs, run the request, and email the user when the results are completed and posted for viewing. The Fort Future web-based software environment has been designed to accommodate the generation and operation of Web-based GUIs through the construction of XML text files.

4.4.2.4. Comparison of End-User Delivery Approaches

RSim, mLEAM, LEAM, and Fort Future have distinctly different approaches and philosophies for delivering capabilities to end users. RSim and LEAM are designed to deliver final capabilities to a local geographic community by tailoring the software, data, and analyses in direct response to locally unique needs. Therefore, application of RSim or LEAM requires that the development group create a new instance of the capabilities. The RSim interface can be provided to the user via CD or the web, which allows users some latitude in posing scenarios without involving the development group. The user can readily develop reports with text, tables, and maps derived from their particular combination of conditions and scenarios. The interface documents the conditions under which the model can be run and provides suggestions for adaptation of RSim to special applications. LEAM developers deliver results to the user community, but not the models. Results are primarily in the form of color reports filled with images and interpretations, but can include GIS map files. mLEAM, like RSim can be delivered to end users, but is in a form useful only to computer technicians familiar with Unix/Linux and GRASS. A set of technical reports have been published that will help the technicians apply mLEAM to other locations. Fort Future LEAM is designed to allow virtually anyone with a Web browser to run mLEAM (or LEAM) simulations. The development/delivery philosophies for applying the models to a new area can be summarized as follows:

- The RSim philosophy is to provide an end user with the ability to run scenarios on any computer or computer operating system using models specifically tailored for the target area and using nationally available data sets. Adapting the model to a new area can most easily be done by the developers of RSim but could be attempted by others.

- The mLEAM philosophy is to provide an end user with a quick way to generate generic urban growth and military impact analyses using nationally available data sets. Users can contract with developers or work with local GIS techs.

- The LEAM philosophy is to deliver analysis and results of urban growth simulation using models tailored to the needs of local planners, calibrated to local trends, using local data, and through the integration of urban growth impact analyses as needed.

- The Fort Future LEAM philosophy is to allow anyone to run mLEAM-type analyses for anywhere in the country – through their Web browser.

Development of an integrated capability will begin by carefully stating the questions that end users will be able to ask, the expense in time and money the user will accept, the accuracy and detail needed by the user, and the skills of the user. Based on this a product development and delivery approach will be defined – followed by design and development.

4.5 Evaluation of Feasibility and Utility of Synthesizing Tools Provided by SERDP SI 1259 and SI 1257

4.5.1 Background

Research projects SI-1257 and SI-1259 were funded by the Strategic Environmental Research and Development Program (SERDP) to build simulation models that address issues of encroaching development around military installations and their implications on both the installation's mission and the condition of the region. The resulting products, RSim, LEAM, and mLEAM, represent a suite of analysis approaches, software tools, and techniques for helping installations identify, predict, and address encroachment challenges.

To evaluate the feasibility and utility of synthesizing the modeling tools being provided by SERDP SI 1259 and SI 1257, the RSim team held a workshop to identify the strength of the RSim approach and had productive conversations with mLEAM researchers to discuss integration approaches. Because the similar process in the two modeling approaches is urban land cover, the way that urban land cover is modeled by the two approaches needs to be described before the concept of synthesizing the tools can be discussed. The next sections first discuss the utility of a combined approach and then compare the way urban land-cover changes occur in the different models. The last section discusses the technical feasibility of synthesizing the modeling tools.

4.5.2 The Utility of Combining the RSim Approach with the mLEAM Approach

The value of combining the RSim and the mLEAM approaches is the breadth and diversity of questions that can be addressed, processes evaluated, and decisions considered. RSim focuses on a diversity of outcomes: how land-use decision affects the quality of the air, water, noise and species and their habitat. It can be run under explicit scenarios of urban growth, military use, road development and hurricanes. These changes are underlain by changes in 18 land cover categories (including developed, barren, forested upland, shrubland, non-natural woody land, herbaceous and wetland classes). LEAM connects proposed regional plans with long-term consequences to transportation networks, utilities, habitat fragmentation, and services such as schools. The mLEAM models focus on providing projections of urban residential patterns and their direct impact on suitable military training/testing areas. Together these models cover a great diversity of cause and effects. Because each model allows some feedbacks, the combined model could be used to explore interactions that might display nonlinear dynamics. Combining the capabilities of the model suites could provide installation and regional planners with the following set of capabilities:

- Explore potential outcomes of a variety of decisions under different scenarios of future change.
- Project economic and population changes in regions based on proposed installation mission changes.
- Forecast future land-cover changes and patterns across regions.
- Forecast effects of changes in the region due to:
  - Urban growth (under typical conditions for the region or other scenarios)
  - Natural disturbances such as hurricanes
  - Changes in the road system
  - New military training areas
- Evaluate the impact of future land-cover changes and their patterns on:
  - Habitat suitability
  - Military training/testing suitability
  - Water quality
  - Air quality
  - Transportation system loads
  - Economic and social impacts
  - Noise conditions

4.5.3 A Focus on Urban Land-Use Change as a Way to Integrate RSim and mLEAM

The key process that is common to the RSim and LEAM/mLEAM land-use change models is urban land-cover change. Both approaches start with initial conditions of a particular spatial configuration of urban lands and project changes over time in urban land use. However the forces that affect urban land cover are quite different in the two approaches.

The mLEAM models simulate changes in urban patterns in response to local, county and state planning. Planning decisions that can be made by users relate to such features as locations of new highways, construction of highway ramps, major land purchases, purchases of development rights construction of news roads, zoning plans, or installation buffers. Hence the LEAM/mLEAM approach focuses on forecasting results of planning decisions. These planning proposals essentially establish the “playing field” upon which residential developers build new homes and neighborhoods and homebuyers purchase their residences, industrial developers create new industrial/commercial areas, and city planners establish new parks and open spaces. The LEAM land-use change model then forecasts these decisions and resulting regional land-use patterns. (mLEAM uses only the residential projection component.) Based on population projections using a multi-sector economic input-output model, target growth in commercial, residential, and open space is pre-calculated. The LEAM land-use change model then converts developable, but undeveloped, land within the region based on the pre-calculated needs and the relative attractiveness of land to each use. The new development then affects the attractiveness of each cell to development, which is recalculated. This process occurs in one-year time steps. The result is captured in two maps. The first is the final land-use map using the National Land Cover Data (NLCD) categories as the starting land-use map. The second captures the time step at which each cell changed. Using these two maps and the starting map, it is simple with a GIS to generate the land use at any time step or to create a movie showing the land-use change over simulation time.

RSim simulates changes in urban land by a rule-based model (Clarke et al. 1998, Clarke and Gaydos 1998, Candos 2002). RSim includes both spontaneous growth or new urban areas and patch growth (growth of preexisting urban patches). Growth occurs in either low-intensity[8] or high intensity[9] urban areas. Any non-urban cells can become low-intensity urban cells according to three rules: spontaneous growth occurs in a set number of random cells; new spreading growth occurs in random cells and two neighboring cells, or edge growth arises from a random number of non-urban pixels with at least three urbanized neighboring cells. This approach to modeling urban growth was derived from the SLEUTH model (http://www.whrc.org/midatlantic/modeling_change/SLEUTH/sltuh_overview.htm).

Low-intensity urban pixels become high-intensity urban cells according to different rules for two types of desired high-intensity urban cells:

- central business districts, commercial facilities, high impervious surface areas (e.g., parking lots) of institutional facilities that are created within existing areas with a concentration of low-intensity urban cells; and
- industrial facilities and commercial facilities (malls) that are created at the edge of the existing clumped areas of mostly low-intensity urban cells or along four-lane roads.

For the first high-intensity category, land-cover changes occur in a manner similar to changes in low-intensity growth, as described above: a spontaneous growth algorithm converts random low-intensity pixels to high-intensity pixels, and an edge growth algorithm converts random low-intensity urban pixels with high-intensity urban neighbors to high-intensity pixels. The second type of conversion from low-intensity to high-intensity urban land use is road-influenced growth.

RSim is initiated with the 1998 land-cover data for the west central Georgia study region that was obtained from the Natural Resource Spatial Analysis Laboratory, University of Georgia and classified into 18 NLCD categories. In addition to considering urban growth, RSim simulates changes in non-urban land cover (i.e., change in forests, cropland, barren area, and so on). In order to incorporate the growth and changes that may happen in non-urban land-cover types, an analysis of past growth trends helped to set specific growth patterns and trends for the future. This approach is based on the assumption that growth trends remain constant over the years of

[8] Low-intensity urban land includes single family residential areas, urban recreational areas, cemeteries, playing fields, campus-like institutions, parks, and schools.

[9] High-intensity urban land includes central business districts, multi-family dwellings, commercial facilities, industrial facilities, and high impervious surface areas of institutional facilities.

analysis and over the spatial area being considered. Since forest management activities are different within Fort Benning and the surrounding private lands, the transition rules were calculated only for regions outside Fort Benning. The land inside the Fort Benning military reservation is maintained for training exercises.

4.6 Receptivity of RSim to Different Data Format, Model Validations, and Future Modeling Needs

4.6.1. Data Format of RSim

This section discusses the data needed to transfer RSim to a new location in terms of its availability, cost, time required, and processes involved.

4.6.1.1 Basic information need to run RSim:

- Land cover – Land cover types at 30 m resolution available from USGS
- Changes in land cover types over time – Land cover data for at least 2 time periods 10 years apart and close to the census periods (e.g., 1980, 1990 or 2000).
- Boundaries of military and other public ownership - available from the state GIS agency or other programs such as the Gap Analysis Program.
- Roads by type (dirt, two-lane, four-lane, interstate) - available from the state GIS agency or the US Census Bureau TIGER data.
- Changes in human population over time - US Census data

4.6.1.2. Water quality

- Hydrological units (HUCs) - available from USGS
- Region-specific export coefficients for nitrogen and phosphorus from different land cover types -- Some coefficients can be derived from studies already published, but in many cases it would be best to have actual field measurements of N and P exports from watersheds that are dominated by a particular land cover type. So that means measurements and field research similar to what ORNL researchers have proposed for the watershed management SON at Fort Benning.

4.6.1.3. Species

- Characterization or location of habitat, foraging area and nesting sites for species of special concern– often this information is better known for rare species than for widely available species.
- Model that identifies habitat for species – Models are available for some rare species (e.g, gopher tortoise, karner blue butterfly, etc.). In cases of widely distributed species, developing such a model may be straightforward. In some case, the habitat to which a species is restricted is not known.

4.6.1.4. Air quality

- Initial emissions, initial ozone air quality concentrations, and sensitivity coefficients (factors relating changes in air quality concentrations relative to changes in emissions) -- Available from the Fall Line Air Quality Study for the entire Eastern United States. Projected changes in future year emissions for all areas are available from the US EPA EGAS4.0 program.

4.6.1.5. Noise

- Peak noise contours – can be developed for Army installations using SARNAM and BNOISE2. Information needed to run the models include range layouts and operational data. USACHPPM is the technology transfer point for the Army noise models and has already developed Peak noise contours for many of the major Army installations.

4.6.1.6. Additional stressors of interest

- Fire (both natural and human induced)
- Particulates in air
- Sedimentation
- Invasive species.

4.6.1.7. Other relevant data

- Soils layers - from the USDA Natural Resources Conservation Service
- Streams data - usually available from the State GIS agency
- Zoning constraints on urbanization, if available

4.6.1.8. Scenarios

- Type of change
    - Proposed roads and road expansions--often available from state transportation offices
    - Proposed military training and extent--often available from installation.
    - Proposed land purchase or lease by military
    - Proposed environmental regulation
    - Potential disturbance
- Potential impact --often available from the scientific or grey literature. However there is poor documentation of the location, frequency, or intensity of some disturbance (e.g., ice storms).
- Potential extent in application area--can use information from other similar disturbances.

4.6.1.9. Cost and processing issues:
Most of the listed geographical data sets are inexpensive (there may be a handling charge of $50 or so for some of the data sets based on the state GIS agencies policy of distributing data). However if new data are collected or generated, cost might be an issue. For example, if new land-cover data would be needed, the cost of buying satellite data and creating the land-cover classes will be involved. Similarly, there may be costs for creating the noise contours if the models need to be run at new locations. If field data need to be collected, then cost will rise.

The time for collecting geographical data is small and the process is straightforward — that is if data are available (soils, roads, streams, boundaries, basic land cover)! Challenges arise when the appropriate data are not available at the right scale or format.

4.6.2. RSim Validation

RSim is a collection of models that simulate changes in the landscape. Validation of this complex set of models can only be done by validation of the models that make up RSim. Where possible, RSim was built upon existing models and thus relies upon model development, testing and validation that has already occurred.

RSim simulates changes in urban land by a well-tested rule-based model (Clarke et al. 1998, Clarke and Gaydos 1998, Candos 2002). The urban growth module of RSim as applied to the five county study region (including and encompassing Fort Benning) was validated by comparing changes in human demographic variables to changes in urban land cover for the five-county study region encompassing Fort Benning (Baskaran et al. 2006A). The RSim urban growth model was run from 1990 for 10 iterations. Each step in the iteration showed an increase in the number or urban pixels. Using the ratio between the population in 1990 (census data) and the urban area in 1990 as a base, the population was estimated for each time step.

The module that predict habitats for the gopher tortoise (*Gopherus polyphemus*) was developed based on analysis of documented locations of gopher tortoise burrows at the Fort Benning military installation in west central Georgia and tested for the five-country region of RSim that falls outside the installation (Baskaran et al. 2006B). Burrow associations with land cover, soil, topography, and water observed within Fort Benning were analyzed with binary logistic regression. This analysis helped generate a probability map for the occurrence of gopher tortoise burrows in the five-county region surrounding Fort Benning. Ground visits were made to test the accuracy of the model in predicting gopher tortoise habitat. The results showed that information on land cover, soils, and distances to streams and roads can be used to predict gopher tortoise burrows for the region.

Nutrient export coefficients have been widely used to predict total N and P losses from landscapes to surface receiving waters (e.g., Beaulac and Reckhow, 1982; Frink, 1991; Johnes, 1996; Mattikalli and Richards, 1996). An export coefficient is the amount of N or P lost annually from a particular land cover type on an area basis (for example, g N m^{-2} yr^{-1}). Export coefficients can be combined with information on the area of different land uses and/or land covers to predict the annual flux of N and P from terrestrial watersheds. Past studies that have compared predicted and measured nutrient loads appear to validate the use of export coefficients for estimating annual watershed losses of both N and P (Johnes, 1996; Johnes et al., 1996; Mattikalli and Richards, 1996).

To understand how noise from military installations may affect the environment, RSim uses GIS data layers of military noise exposure developed by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) as part of the Fort Benning Installation Environmental Noise Management Plan (IENMP). RSim builds upon noise guideline levels developed by the military under the Army's Environmental Noise Program [ENP] (U.S. Army. Army Regulation 200-1. 1997). ENP guidelines define zones of high noise and accident potential and recommend uses compatible in these zones. Local planning agencies are encouraged to adopt these guidelines. IENMP contains noise contour maps developed from three DoD noise simulation models: NOISEMAP, BNOISE, and SARNAM.

- The Army, Navy, and Air Force use NOISEMAP (Version 6.5), a widely accepted model that projects noise impacts around military airfields. NOISEMAP calculates contours resulting from aircraft operations using such variables as power settings, aircraft model and type, maximum sound levels and durations, and flight profiles for a given airfield.

- The Army and the Marines use BNOISE to project noise impacts around ranges where 20-mm or larger caliber weapons are fired. BNOISE takes into account both the annoyances caused by hearing the impulsive noise of weapons and by experiencing house vibration caused by the low frequency sound of large explosions. BNOISE uses operational data on the number of rounds of each type fired from each weapon broken down by day and night firing. Contours show the cumulative noise exposure from both firing point and target noise.
- All the military services use the Small Arm Range Noise Assessment Model (SARNAM) to project noise impacts around small arms ranges. SARNAM is designed to account for noise attenuated by different combinations of berms, baffles, and range structures.

Each model produces noise contours that identify areas where noise levels are compatible or incompatible with noise-sensitive land covers. Based on U.S. Army attempts to validate human annoyance predictions based on noise contours, the Department is considering a new recommendation to use peak sound levels rather than the current metrics.

The Air Quality Module in RSim estimates the impact of those emissions changes on ozone air quality using sensitivity coefficients recently available from another air quality study of middle Georgia (the Fall line Air Quality Study: http://cure.eas.gatech.edu/faqs/index.html). This study is based on measurements of ozone, as well as models. Sensitivity coefficients from that study relate the changes in emissions to changes in air quality. The final report of the Fall line Air Quality study presents an uncertainly analysis.

4.6.3. Future Modeling Needs for RSim

4.6.3.1. Burning scenario

During discussion with several colleagues at the 2005 SERDP Symposium, we were struck by the importance of burning for forest management at Fort Benning. Local burning may affect forest development and hence habitats for red-cockaded woodpecker. Regionally burning may affect air quality. Yet our initial proposal for RSim did not include a burning scenario.

A burning scenario could be added to RSim by building off of the model of prescribed burning and forest thinning that Garten (2006) developed at Fort Benning. This model allows examination of different levels of fire intensity and return frequency. These effects can be incorporated into the RSim code to affect nitrogen exports, air quality, and land cover changes as well as their subsequent effects on habitat for red-cockaded woodpecker and gopher tortoise.

The benefit of including the burning scenario in RSim is that the model can then be used to explore the impacts of burning on several types of environmental impacts. Burning is such a critical management issue at Fort Benning that we suspect the users will be disappointed if RSim does not include this important activity.

4.6.3.2. Testing the general applicability of RSim by transporting it to a new installation and region.

Modifying and applying RSim to another location requires that the general applicability of the model be examined. In that case, stakeholders from the new region would be engaged in the development, testing, and use of RSim throughout the project. A stakeholder analysis will be conducted early to determine the key scenarios to be used in the modeling effort. Relevant scenarios to consider include (but are not limited to) urban and suburban growth, sea level changes, changes in temperature and/or precipitation, hurricanes, introduction and spread of nonnative species, and military training. RSim's forecasting accuracy would be tested by running it using recent historical cases as scenarios and by comparing model output to data already collected for the region. This task would thus require choosing a region where such historical data are already available.

To fully understand how RSim can be used to improve resource management in the new region, RSim would be deployed in three modes: (1) an integration test to examine how well RSim can deal with multiple resource management goals, (2) conservation education and environmental awareness, and (3) support for adaptive management. Technology transfer would best be accomplished by actively engaging stakeholders throughout the study, delivering the RSim model to environmental managers at the installation and holding a workshop with members of the stakeholder community to demonstrate use of the forecasting tool.

4.7 Backcasting Component of RSim and Testing RSim by Comparison to Growth Trends for the Region

4.7.1 Introduction

Growth and development of human settlement is an inherent aspect of societies. With more awareness of the environmental implications of growth and with more regulations in place that are affected by growth, the need to plan any development is important. A good understanding of the implications of such activities can assist in foreseeing negative effects they may have on the environment and society.

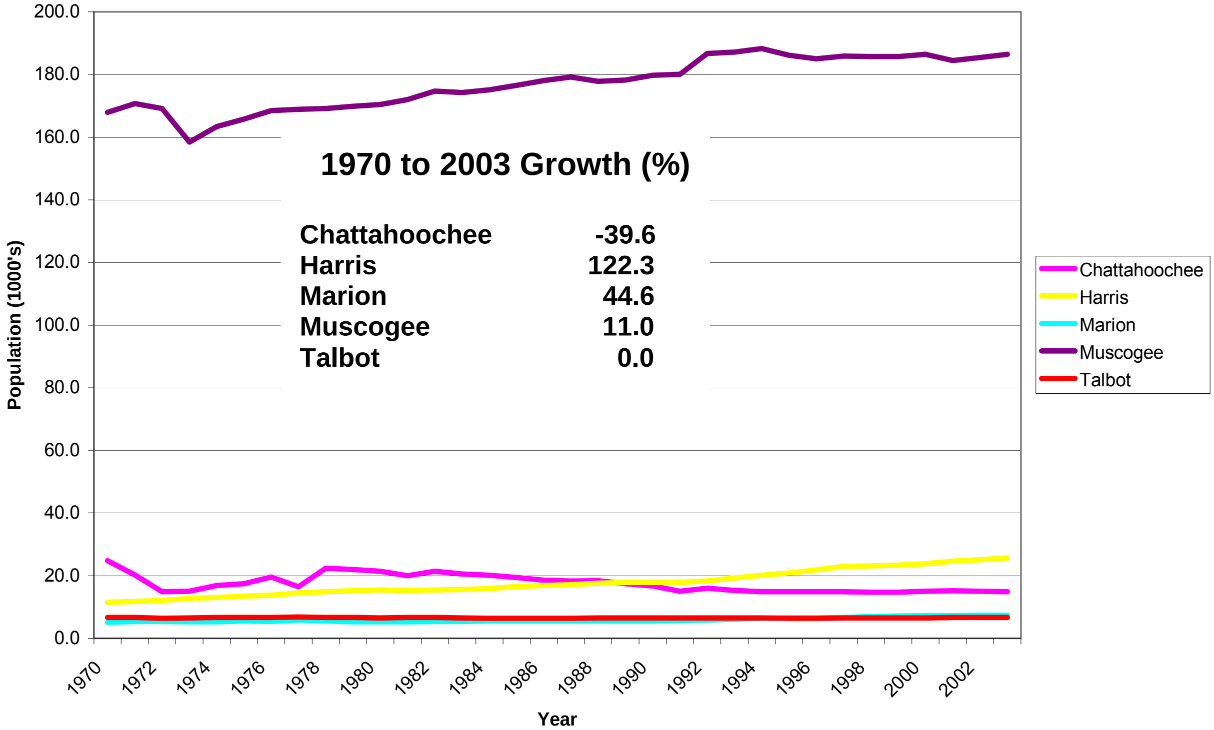
The Regional Simulation Model (RSim) explores resource use and constraints as dictated by growth and development issues in and around Fort Benning, Georgia. Four scenarios are considered and simulated in the model – urban growth, proposed road improvement plan in Georgia, a new training area in Fort Benning, and hurricanes. Backcasting was done with RSim in the sense that the model was initiated in 1990 and used to project forward to 1998. The challenge in such an effort is always obtaining consistent data across the time intervals. We were frustrated to find differences in the land-cover categories adopted by different groups of researchers making it impossible to compare model projections using these categories.

4.7.2 Population trends in the study region

Analyses involving different demographic and economic characteristics such as population, employment in various sectors, market value of commodities, and income and commuting patterns have been done for each of the five counties in the study region for different years by

David Vogt and Colleen Rizy, Regional Study Program, Environmental Science Division, ORNL. The major population growth trends within the RSim counties are presented in Figure 37. As can be seen from the graph, the growth trends are vastly different among the counties. Harris County has the fastest growth rate whereas Chattahoochee County has seen a decline in growth. The 1970, 1980, 1990, and 2000 Census data were also used to produce a time-series of detailed (i.e., tract level) economic characteristics, such as urban vs. rural density and housing stats. A grid-based database of economic characteristics of 1990 and 2000 population data was also prepared by Vogt and Rizy.

Figure 37. Total population for the five counties in Rsim (1970-2003).



4.7.3 Description of 1990 and 1998 land cover

RSim model runs originate from a base year of 1998. The 1998 land cover data for the study region was obtained from the Natural Resource Spatial Analysis Laboratory, University of Georgia. The 18 class land-cover map was originally generated from Landsat TM images. A description of all the classes is presented in Supplement A in Appendix A4. The resolution of the data is 30m.

For model calibration of RSim, the 1990 land-cover data were also used. The 1990 land-cover map was created by the Georgia Department of Natural Resources. This data set has 12 land-cover classes and a description of the classes is listed in Supplement B in Appendix A4. The map is based on Landsat TM imageries dated 1988 to 1990 and has a resolution of 60m. For this study, the land-cover data was resampled to 30m in order to match the 1998 land-cover resolution.

4.7.4 Urban growth time step estimation

Initially the rate of growth was estimated for the whole study region, i.e., the five counties. Subsequently county-wise estimates were made. Several approaches for estimating the length of a model run were carried out. Other approaches were not suitable for this study because of data constraints and nature of the study region. However, all the approaches are outlined in the following sections. The primary approach was the one most suitable to calculate the time step of the model.

4.7.4.1 Primary Approach

The RSim model was run from 1990 for about 10 iterations. Each iteration indicated an increase in the number or urban pixels (low intensity urban and high intensity urban classes). Using the ratio between the population in 1990 (Census data) and the urban area in 1990, the population was estimated for each time step. This analysis is shown in table 19.

Comparing the growth in population from 1990 to 2000, with the growth in population from 1990 to the first time step gives an estimate of the number of years for one step (Table 30). In this case, one time step corresponds to approximately 11.7 years.

Table 29: Population estimation based on 1990 urban area and population.

Data	**Area of Urban (hectare)**	**Population**
Original – 1990	11984.70788	226114
Time step 1	12756.64591	240678.0593
Time step 2	13566.11623	255950.2355
Time step 3	14363.31638	270990.912
Time step 4	15176.39557	286331.1765
Time step 5	16022.67639	302297.8521
Time step 6	16882.31005	318516.4539
Time step 7	17726.42555	334442.2766
Time step 8	18588.58542	350708.5401
Time step 9	19477.09007	367471.8473
Time step 10	20345.02414	383847.0519

Table 30. Time step calculation based on 1990 urban area and population.

	Change in population	**Number of years**
1990 to 2000	12396	10 Years
1990 to timestep1	14564.05927	11.74899909

Similar calculations were carried out by changing the ratio used to estimate the population of each time step. A calculation based on the year 2000 ratio of urban area and population yielded a longer time step of approximately 18 years for one iteration (Tables 31 and 32). The two estimates using 1990 and 2000 population-urban area ratios can be used to bound the timestep by their values of relatively slower growth and faster growth.

Similar analysis using measures such as population within urban pixels and number of people per pixel were attempted but were not appropriate since the estimated values for 2000 were lower than that of 1990. This difference can be due to the way in which population was gridded in the region by the US Census for the different years (2000 population is more widely spread than the 1990 population).

Table 31. Population estimation based on 2000 urban area and population.

Data	Area of Urban (hectare)	Population
Original - 1998 (2000)	12244.86	238510
Time step 1	12756.64591	248478.7589
Time step 2	13566.11623	264245.927
Time step 3	14363.31638	279774.092
Time step 4	15176.39557	295611.5551
Time step 5	16022.67639	312095.7321
Time step 6	16882.31005	328840.0007
Time step 7	17726.42555	345282.0007
Time step 8	18588.58542	362075.4757
Time step 9	19477.09007	379382.1042
Time step 10	20345.02414	396288.0512

Table 32. Time step analysis based on 2000 urban area and population.

	Change in population	**Number of years**
1990 to 2000	12396	10 Years
1990 to timestep1	22364.75894	18.04191589

The above calculations were for the summed five county extent in the study region. Similar calculation carried out for individual counties yielded varying results. The population in some of the counties (Chattahoochee and Talbot) has been declining over the past few years. The Census data indicates this change, but the RSim growth rules are not sensitive to such population decline. Hence the urban areas show an increase in all counties. Such a trend is not directly comparable to the population information.

In counties showing an increase in population (Harris, Marion and Muscogee), three different time step rates were obtained. Marion – 4.3 years, Harris – 1.9 years and Muscogee – 17.6 years. These differences can be attributed to the rate of growth of each county and the presence of new or old growth situations

4.7.4.2 Alternative Approaches

4.7.4.2.1 Population potential

A simple way to obtain population potential is by considering the density of each point (pixel) over a fixed region. A regional extent is considered since the original population grid does not exactly identify locations of houses/settlements (they are randomly placed), it would not be appropriate to consider density at each grid. Some kind of smoothing should be done to account for the random placement.

4.7.4.2.2 Based on urban and rural population

By comparing urban areas of the land cover simulations and the urban and rural population information from the Census, estimates of the change in urban population by urban area can be developed and used to identify the time frame of a model run. An example of the urban and rural breakup of the demographic data is presented in Table 33. The definition of each of the Census population categories relating to urban and rural classifications is provided in Appendix A4.

This approach was not useful in this study because of differences in definitions of urban area of land-cover data and the definition of urban and rural population by the Census. The land-cover data has two categories for urban areas – low intensity urban and high intensity urban (refer to Appendix A4). These categories of urban area are based on the extent of buildings, roads and concrete as seen by a sensor. It does not entirely imply the population in that region. Hence the urban area land cover could not be equated to the urban population of a region.

Table 33. 1990 and 2000 Urban and Rural Population Demographics by County.

	Chattahoochee County		**Harris County**		**Marion County**		**Muscogee County**		**Talbot County**	
	1990 - County	2000 – County	1990 - County	2000 – County	1990 - County	2000 – County	1990 - County	2000 – County	1990 - County	2000 – County
Urban:	86%	79%	4%	3%	0%	0%	97%	97%	2%	0%
Inside urbanized areas	86%	79%	0%	0%	0%	0%	97%	97%	0%	0%
Inside urban clusters	0%	0%	4%	3%	0%	0%	0%	0%	2%	0%
Rural:	14%	21%	96%	97%	100%	100%	3%	3%	98%	100%
Farm	0%	0%	3%	1%	7%	4%	0%	0%	5%	6%
Nonfarm	14%	21%	93%	96%	93%	96%	3%	3%	93%	94%

4.7.4.3 Time step calibration

The time step estimate of 11 to 18 years for one model run was considered very high for the RSim study. Finer temporal estimates were required. Hence the parameters for the growth rules were adjusted such that growth was much slower. After this calibration, one time step corresponded to approximately one year.

4.8 User Interface

Work was completed on transitioning the user interface to one that is suitable for expected end-users. This involved creating an easily navigable interface for selecting appropriate scenarios and optionally setting custom model parameters along with simulation output options. While model outputs can be saved to disk for future reference and analysis by advanced users, the user interface design work also includes a mechanism for some high-level exploration of the results of each RSim model, which allows the user to save customized model parameters for future use. The interface is now a part of the RSim CD.

In order to gauge how resource managers might use RSim, a meeting was held on February 23, 2005 at the Columbus Chamber of Commerce with resource mangers from the five county area (see attached Appendix A3). The purpose of this meeting was to inform local resource managers of the development of RSim and to get their input on design of RSim and its interface.

5. Conclusions

The use of RSim to explore regional changes in west, central Georgia projects that high urban growth can have dramatic impacts upon water and noise quality and upon the habitat of one species of special concern (gopher tortoise) but not another (red-cockaded woodpecker). Hence, this example illustrates where management attention might be focused in order to promote environmental sustainability of the region. However, only a limited set of conditions were considered in this example. The ongoing and regular use of this type of model in a planning environment is the most effective way to make use of the approach. Simulation models offer a cost-effective and efficient means to explore potential outcomes of resource management and land use. This analysis shows that modeling, understanding and managing for effects of land-use change on several sectors (air, water, noise, and habitat) requires attention to the spatial and temporal scale at which each sector operates and how the factors influencing the sectors interact.

The way in which RSim fits into bioregional planning for central Georgia is described in depth in Dale et al. (2006): A component of regional activities is county-level planning, which became a requirement in Georgia as a result of the 1989 Georgia Planning Act. The planning process is managed by the Georgia Department of Community Affairs. It should be noted, however, that counties are not required to implement the plans that the State creates, and therefore it is important to communicate with county planners about the validity of these plans. Also, plans do not include map coordinates.

We obtained Comprehensive Zoning Plans for Harris, Chattahoochee, and Talbot counties from Patty Cullen, executive director of the Lower Chattahoochee Regional Development Center. We obtained the zoning plan for the Columbus-Muscogee County unified government from the world-wide web at http://www.georgiaplanning.com/planspub1/. Additional information is available from the Valley Partnership Joint Development Authority, which is a potential stakeholder in our modeling effort. The Valley Partnership Joint Development Authority (VPJDA) is a multi-governmental entity created by local governments from the City of Manchester, City of West Point and the counties of Chattahoochee, Harris, Marion, Muscogee, Talbot and Taylor, Georgia.

With additional coordinates, land use maps from these plans could be used to digitize particular, future land cover types, as an alternative to implementing the urbanization algorithms in RSim. RSim already has an option for digitizing future roads, for example, highways in the Governor's Road Improvement Program (GRIP). Thus, particular future land uses would have to be translated to one of the 44 land cover types available in the Georgia Gap Program. However, the land cover types that are depicted in the county zoning plans may not be accurate for one of several reasons: 1) as noted above, counties are not required to implement their plans; 2) plans are continually changing; and 3) land use designations in the plans do not typically consider topography, so land that is marked as residential land on the plans will not all be low-intensity urban land cover; and 4) many of the land use types can translate into one or more land cover types (e.g., "agriculture/open space" can refer to "pasture, hay," "rowcrop," "clearcut-sparse vegetation," or "parks, recreation"). Therefore, the use of these plans is not necessarily more accurate than the use of the RSim urbanization algorithms. Also, the urbanization algorithms of RSim are needed for counties where no plan maps are available (e.g., Marion County). The best use of these plans might be to locate future and current industrial parks and recreational parks and to digitize these to add as a layer to RSim. The key benefic of RSim over static plans is that RSim promotes learning about environmental affects of specific decisions in the region.

In summary, RSim is a useful tool for exploring the implications of land use and management decisions on the environment of the five-country area around Fort Benning, Georgia. The environmental conditions include air quality, noise, nutrient export and the key rare species in the region (gopher tortoise and RCW). The scenarios implemented are the new DMPRC at Fort Benning, proposed road improvements, increased urban growth, and a hurricane. A user interface has been developed to make the tool accessible. Potential next steps include adding a burning module and testing RSim in a new region. The use of RSim in a management and learning mode should reveal the kinds of effects that might be expected from specific actions.

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Appendix A: Supporting Data

Appendix A1. Data used in reported model runs

Table A1. Select Scenarios

Land cover transitions selected?	YES
Military expansion scenario selected?	YES
Hurricane scenario selected?	NO
Number of time steps (yrs)	40

Table A2. Urban Growth Model Parameters

Parameter	Business as usual	High urban growth
Dispersion (Low)	6.0	6.0
Dispersion (High)	5.0	5.0
Breed (spread)	4.0	4.0
Breed (roads)	15.0	15.0
Spread (Low)	0.9	90.0
Spread (High)	0.5	50.0
Road Search (High)	13.0	13.0
Road Search Distance (Low)	1000.0	1000.0
Road Search Distance (High)	5000.0	5000.0
Road Trip Energy	200	200

Table A3. Land Cover Transitions

	Deciduous	Evergreen	Mixed	Clearcut	Pasture	Row Crops	Forested Wetland
Deciduous		1.8	0.1	0.8	0.5	0.0	0.5
Evergreen	1.3		0.1	1.6	0.5	0.0	0.0
Mixed	4.1	4.2		1.0	0.5	0.0	0.2
Clearcut	1.3	7.8	0.1		0.7	0.0	0.1
Pasture	0.7	1.0	0.0	0.4		0.0	0.0
Row Crops	0.8	1.4	0.0	1.0	5.6		0.0
Forested Wetland	3.8	1.5	0.1	0.7	0.2	0.0	

Table A5. Water Quality Module Export Coefficients

	kg N/ha/yr	kg P/ha/yr
Wetland	5.5	0.25
Forest	1.8	0.11
Pasture	3.1	0.1
Idle	3.4	0.1
Industrial	4.4	3.8
Residential	7.5	1.2
Row Crops	6.3	2.3
Business	13.8	3.0

Table A6. Air Quality Conditions

Selected meteorological episode	Mild ozone episode
Mobile sources	1.0
Area sources	1.0
Non-road sources	1.0
Point sources	1.0

Table A7. Noise Conditions

Noise module selected?	YES

Table A7. Species and Habitats Conditions

RCW module selected?	YES
Gopher tortoise habitat module selected?	YES
Cutoff probability for burrow presence	0.8
Threshold habitat patch size (ha)	2.0
Minimum patch size applied?	NO

Appendix A2. Data Requirements for RSim

Basic information:

- Land cover – Land cover types at 30 m resolution available from USGS
- Changes in land cover types over time – Land cover data for at least 2 time periods 10 years apart and close to the census periods (e.g., 1980, 1990 or 2000).
- Boundaries of military and other public ownership - available from the state GIS agency or other programs such as the Gap Analysis Program.
- Roads by type (dirt, two-lane, four-lane, interstate) - available from the state GIS agency or the US Census Bureau TIGER data.
- Changes in human population over time - US Census data

Water quality

- Hydrological units (HUCs) - available from USGS
- Region-specific export coefficients for nitrogen and phosphorus from different land cover types -- Some coefficients can be derived from studies already published, but in many cases it would be best to have actual field measurements of N and P exports from watersheds that are dominated by a particular land cover type. So that means measurements and field research similar to what ORNL resaechers have proposed for the watershed management SON at Fort Benning.

Species

- Characterization or location of habitat, foraging area and nesting sites for species of special concern– often this information is better known for rare species than for widely available species.
- Model that identifies habitat for species – Models are available for some rare species (e.g, gopher tortoise, karner blue butterfly, etc.). In cases of widely distributed species, developing such a model may be straight forward. In some case, the habitat to which a species is restricted is not known.

Air quality

- Initial emissions, initial ozone air quality concentrations, and sensitivity coefficients (factors relating changes in air quality concentrations relative to changes in emissions) -- Available from the Fall line Air Quality Study for the entire Eastern United States. Projected changes in future year emissions for all areas are available from the US EPA EGAS4.0 program.

Noise

- Peak noise contours – can be developed for Army installations using SARNAM and BNOISE2. Information needed to run the models include range layouts and operational data. USACHPPM is the tech transfer point for the Army noise models and has already developed Peak noise contours for many of the major Army installations.

Additional stressors of interest

- Fire (both natural and human induced)
- Particulates in air
- Sedimentation
- Invasive species.

Other relevant data

- Soils layers - from the USDA Natural Resources Conservation Service
- Streams data - usually available from the State GIS agency
- Zoning constraints on urbanization, if available

Scenarios

- Type of change
    - Proposed roads and road expansions--often available from state transportation offices
    - Proposed military training and extent--often available from installation.
    - Proposed land purchase or lease by military
    - Proposed environmental regulation
    - Potential disturbance
- Potential impact --often available from the scientific or grey literature. However there is poor documentation of the location, frequency, or intensity of some disturbance (e.g., ice storms).
- Potential extent in application area--can use information from other similar disturbances.

Cost and processing issues:
Most of the listed geographical data sets are inexpensive (there may be a handling charge of $50 or so for some of the data sets based on the state GIS agencies policy of distributing data). However if new data is collected or generated, cost might be an issue. For example if new land-cover data would be needed, the cost of buying satellite data and creating the land-cover classes will be involved. Similarly, there maybe costs for creating the noise contours if the models need to be run at new locations. If field data is needed to be collected, then cost will rise.

The time for collecting geographical data is small and the process is straight forward - that is if data is available (soils, roads, streams, boundaries, basic land cover)! Challenges arise when the appropriate data are not available at the right scale or format.

Appendix A3. Summary of February 23, 2005 meeting

Using a Simulation Model to Understand Environmental Impacts in the Five County Region *(Chattahoochee, Harris, Marion, Muscogee, and Talbot)*

RSim is a Regional Simulation to explore impacts of resource use and constraints, that is funded by the Strategic Environmental Research and Development Program (SERDP: http://www.serdp.org/). RSim is being designed to integrate environmental effects of on-base training and testing and off-base development. Effects considered include air and water quality, noise, and habitats for endangered and game species. A risk assessment approach is being used to determine impacts of single and integrated risks. The plan is to make the simulation environment available via web interface. The model is being used in a gaming mode so that users can explore repercussions of military and land-use decisions. A summary of the RSim project is available at: http://www.esd.ornl.gov/programs/SERDP/RSim/ .

The RSim interface will therefore allow managers and planners from both within the Installation and its regional partners to interact with the model and learn more about the interdependence of resource use. The building of the model will identify these relationships and provide a shared format for the consideration of mutually beneficial development.

It is necessary that regional managers and planners participate in the development of the model interface and identify the components of the model that will be most useful for their needs. On Wednesday, February 23rd, a two hour meeting was held by the RSim team (Dr. Virginia Dale and Murray Browne) to introduce the project to the Installation managers and community planners. This meeting also served to establish contacts between the RSim team and the end users of the product.

The list of attendees follows:

Last Name	First Name	Business Affilitation	E-Mail	Telephone
Dale	Virginia	Oak Ridge National Laboratory	dalevh@ornl.gov	865-576-8043
Browne	Murray	University of Tennessee	mbrowne@cs.utk.edu	865-974-3510
Hadden	Biff	Greater Columbus Chamber of Commerce	bhadden@columbusgachamber.com	706-327-1566, x17
Lusk	Rita	Greater Columbus Chamber of Commerce	rlusk@columbusgachamber.com	706-327-1566, x34
Clark	Ken	Marion County Development Authority	thepines@sowega.net	229-649-6303
Cullen	Patti	Lower Chattahoochee RDC	pcullen@jcrdc.org	706-256-2933
Davis	Steve	Columbus Water Works	sdavis@cwwga.org	706-649-3470
Garrard	Bob	Garrard Consulting	garv4665@bellsouth.net	706-323-4868
Harrison	Wade	The Nature Conservancy	wharrison@tnc.org	706-682-0104
Johnson	Slade	Talbot County Development Authority	jsladej39@hotmail.com	706-665-3598

Lynd	Jackie	Ft. Benning	jacqueline.lynd@us.army.mil	706-545-1296
McDaniel	Dorothy	Georgia Conservancy	dmcdaniel@gaconservancy.org	706-718-6856
Mote	Stacy	Consolidated Resources	stacymote@bellsouth.net	706-317-5942
Parris	Steve	USFWS	steve_parris@fws.gov	706-544-6999
Slay	Brant	The Nature Conservancy	bslay@tnc.org	706-682-0217
Steverson	Kathy	Greater Columbus Chamber of Commerce	ksteverson@columbusgachamber.com	706-327-1566, 37
Tant	Bob	Columbus Water Works	btant@cwwga.org	706-649-3432
Turner	Billy G.	Columbus Water Works	bturner@cwwga.org	706-649-3430
Veenstra	Linda	OSJA, Ft. Benning, GA	linda.veenstra@us.army.mil	706-545-8072
Westbury	Hugh	ERDC CERL	hugh.westbury@benning.army.mil	706-545-7882

Appendix A4. Information used in Backcasting run of RSim

Supplement A: Land-cover classes in 1998 land-cover data

(1) **Beaches/Dunes/Mud** - This class includes the following categories of information; beaches, exposed sandbars, sand dunes, mud, dredge materials, and exposed lakeshore.

(2) **Open Water** - This class includes all types of water bodies: lakes, rivers, ponds, ocean, industrial water, and aquaculture, which contained water at the time of image acquisition.

(3) **Transportation** - This class includes roads, railroads, airports, and runways.

(4) **Utility Swaths** - This class includes vegetated linear features, which are maintained for transmission lines and gas pipelines.

(5) **Low Intensity Urban** - This class includes; single family residential areas, urban recreational areas, cemeteries, playing fields, campus-like institutions, parks, and schools.

(6) **High Intensity Urban** - This class includes central business districts, multi-family dwellings, commercial facilities, industrial facilities, and high impervious surface areas of institutional facilities.

(7) **Clearcut/Sparse** - This class includes areas that had been clearcut within the past 5 years, as well as areas of sparse vegetation.

(8) **Quarries/Strip Mines** - This class includes; mines and exposed rock and soil from industrial uses, gravel pits.

(9) **Rock Outcrop** - This class includes geological features such as rock outcrops, and exposed

mountaintops.

(10) **Deciduous Forest** - This class is composed of forests, which contain at least 75% deciduous trees in the canopy, deciduous mountain shrub/scrub areas, and deciduous woodlands.

(11) **Evergreen Forest** - This class is composed of forests, which contain at least 75% evergreen trees, pine plantations, and evergreen woodlands.

(12) **Mixed Forest** - This class includes forests with mixed deciduous/coniferous canopies, natural vegetation within the fall line and coastal plain ecoregions, mixed shrub/scrub vegetation, and mixed woodlands.

(13) **Golf Courses** - Golf courses.

(14) **Pasture** - This class includes pastures, and non-tilled grasses.

(15) **Row Crop** - This class includes row crops agriculture, orchards, vineyards, groves, and horticultural businesses.

(16) **Forested Wetland** - This class includes all types of forested and shrub wetlands.

(17) **Coastal Marsh** - Coastal freshwater and brackish marsh.

(18) **Non-forested Wetland** - This class includes all freshwater emergent wetlands.

Supplement B: Land-cover classes in 1990 land-cover data

(1) **Open Water.** Lakes, reservoirs, coastal waters, ponds and wide stream channels with little or no emergent vegetation are included in this class. On the unclassified imagery, open water appears dark, similar to shadows behind northwest-facing slopes; therefore, some shadow areas are included.

(2) **Clearcut/Young Pine**. The spectral characteristics recently cleared in timber harvest operations and planted to pine or left unplanted are usually quite different from those of other land-cover types. The clearcuts are often large in area and regularly shaped. The typical clearcut/young pine stand has widely-spaced woody vegetation with a ground cover of herbs and grasses. This vegetation type can be seen as transitional to closed-canopy coniferous forest. Any cleared land can be spectrally similar to timber clearcuts, including some agricultural land such as abandoned pasture and fallow cropland.

(3) **Pasture**. Pasture land is distinguished from other agricultural land by the presence of low-growing herbaceous vegetative cover year round. This class includes actual pastures, as well as lawns, fields, and other open areas within urban areas. Pasture can be spectrally similar to

cultivated fields that have vegetative cover during the winter. Pixels of the clearcut/young pine and cultivated/exposed earth classes are often found intermingled.

(4) **Cultivated/Exposed Earth.** Agricultural fields with no winter vegetation, and any other areas where vegetation has recently been removed, exposing soil or rock, are represented by this class. Exposed banks around reservoirs with low water levels often are included in this class. Some cultivated fields showing winter vegetation are spectrally similar to pasture. This class may be found within urban areas and in conjunction with the pasture and clearcut/young pine classes in other areas.

(5) **Low Density Urban.** The high reflectivity of man-made structures in urban areas provides for some separation of urban classes from the non-urban classes. The low density urban class represents urban areas with moderate vegetative cover. However any area with high reflectivity, such as isolated industrial sites, may fall into this or the high density urban class. The edges of some bodies of water are spectrally similar to this class. It is typical for residential areas to be shown as a matrix of this class and forest
class pixels. Low density urban may be interspersed with high density urban.

(6) **High Density Urban.** This class is distinguished from low density urban by an even higher reflectivity of the land cover. Paved areas with buildings and little vegetation are typical of this land-cover class. Roads are often shown as linear features composed of high and low density urban pixels. High density urban pixels found outside of urban areas are indicative of any type of highly reflective structure/ feature such as power substations, grain storage bldgs.

(7) **Emergent Wetland.** Emergent wetlands are spectrally and ecologically transitional between open water and scrub/shrub wetlands. Freshwater marsh vegetation with few woody plants interspersed is typical of the cover type. Where clusters of emergent wetland pixels are found, other wetland types and open water are often in proximity. This class may show up in some non-wetland areas with low-reflectivity cover.

(8) **Scrub/Shrub Wetland.** Intended for wetland vegetation dominated by woody plants less than 20 feet in height, this class contains areas in transition between emergent and forested wetlands. This class is usually found in conjunction with other wetland classes. Where uplands with woody vegetation border open water, pixels from this class may be shown. When found singly within a matrix of low urban density and forest pixels, it is more likely that cover spectrally similar to but not actually scrub/shrub wetland is being shown (i.e., scrubby vegetation over some low-reflective surface).

(9) **Forested Wetland**. Where spectral differences are pronounced, this class may be distinguished from scrub/shrub wetland and upland forest types. Where upland tree canopies overhang river banks or edges of water bodies, pixels from this class may show. These edges may or may not be actual wetlands. Areas of swamp are often shown as mixtures of forested wetland and hardwood forest pixels. Individual or small clumps of pixels in this class when found scattered throughout urban areas may be showing non-wetland areas with spectral similarity to wetlands, such as woody vegetation over low-reflective surfaces. Classification of forested wetlands dominated by deciduous trees is probably more accurate than that in areas with

evergreen, closed canopies. In the latter case, the low reflectivity of the wet areas underneath the canopy may not be picked up by the sensor, making them difficult to distinguish from upland evergreen forest canopies. Spectral similarity between this class and shadows behind northwest-facing slopes may account for the presence of forested wetland pixels shown on some slopes.

(10) **Coniferous Forest.** The uniformity of large tracts of planted pines provides for accurate classification of this land-cover type in upland areas. These stands may be fringed or bisected by the other forest types. Spectral similarity with evergreen hardwood forest in the Coastal Plain may result in difficulty in distinguishing between these two cover types. Where pine canopies are dense, as is often the case, it may be difficult to determine whether the sites are upland or wetland.

(11) **Mixed Forest.** Typically, this class represents mixed stands of hardwood and coniferous trees, neither type exceeding 60-70 percent of the stand. Pine plantations in transition from early stages to forest may be shown in this class, although few if any hardwood trees may be present. Edges of coniferous stands and areas of transition between coniferous and hardwood forest are often shown with this class. Also included may be abandoned cut-over areas.

(12) **Hardwood Forest**. Stands of deciduous hardwoods are generally distinguished from forested wetlands and other forest classes accurately. Evergreen hardwood forests may be spectrally similar to mixed and coniferous classes, and, due to a closed canopy, may be difficult to distinguish from evergreen forested wetlands. River floodplains are often depicted as a mixture of forested wetland and hardwood forest pixels, with drier areas shown as hardwood forest. Cut-over lands with young, shrubby hardwood growth, although not forest, may make up part of this class.

Supplement C: Description of urban and rural descriptors in Census statistics

- **Urbanized Areas** - (UA) An area consisting of a central place(s) and adjacent territory with a general population density of at least 1,000 people per square mile of land area that together have a minimum residential population of at least 50,000 people. The Census Bureau uses published criteria to determine the qualification and boundaries of UAs
- **Urban Clusters** - A densely settled territory that has at least 2,500 people but fewer than 50,000. New for Census 2000.
- **Urban** - All territory, population and housing units in urbanized areas and in places of more than 2,500 persons outside of urbanized areas. "Urban" classification cuts across other hierarchies and can be in metropolitan or non-metropolitan areas.
- **Urban Area** - Collective term referring to all areas that are urban. For Census 2000, there are two types of urban areas: urban clusters and urbanized areas.
- **Rural** - Territory, population and housing units not classified as urban. "Rural" classification cuts across other hierarchies and can be in metropolitan or non-metropolitan areas.
- **Farm Residence** - Dwelling or household located in a rural farm area and concerned with growing crops or raising livestock.

- **Census county division (CCD)** - A subdivision of a county that is a relatively permanent statistical area established cooperatively by the Census Bureau and state and local government authorities. Used for presenting decennial census statistics in those states that do not have well-defined and stable minor civil divisions that serve as local governments.
- **Place** - A concentration of population either legally bounded as an incorporated place, or identified as a Census Designated Place (CDP) including comunidades and zonas urbanas in Puerto Rico. Incorporated places have legal descriptions of borough (except in Alaska and New York), city, town (except in New England, New York, and Wisconsin), or village.

Appendix B. List of Technical Publications

Summary
Journal articles: 7 (1 in review)
Book chapters and proceedings: 4
Reports: 1
Presentations: 19 (4 in symposia and 4 as plenary lectures)
Posters: 13

Web Site: http://www.esd.ornl.gov/programs/SERDP/RSim/index.html

Publications

Baskaran, L.M., V. H. Dale, and W. Birkhead. 2005. Habitat modeling within a Regional Simulation Model (RSim) environment. Pages 6-16 in the Proceedings of the 4th Southern Forestry and Natural Resource Management GIS Conference, Athens, GA, December 16-17, 2004.

Baskaran, L.M., V.H. Dale, R. A. Efroymson, and W. Birkhead. 2006. Habitat modeling within a regional context: An example using Gopher Tortoise. American Midland Naturalist 155: 335-351.

Baskaran, L., V. Dale, C. Garten, D. Vogt, C. Rizy, R. Efroymson, M. Aldridge, M. Berry, M. Browne, E. Lingerfelt, F. Akhtar, M. Chang and C. Stewart. 2006. Estimating land-cover change in RSim: Problems and constraints. *Proceedings for the American Society for Photogrammetry and Remote Sensing 2006 Conference*, Reno, NV, May 1-5 2006.

Dale, V.H., S. Bartell, R. Brothers, and J. Sorenson. 2004. A systems approach to environmental security. *EcoHealth* 1:119-123.

Dale, V.H, Duckenbrod, D., Baskaran, L., Aldridge, M.., Berry, M., Garten, C., Olsen, L., Efroymson, R., and Washington-Allen, R. 2005. Vehicle impacts on the environment at different spatial scales: Observations in west central Georgia. *Journal of Terramechanics* 42: 383-402.

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Efroymson, R.A., V.A. Morrill, V.H. Dale, T.F. Jenkins, and N.R. Giffen. In press. Habitat disturbance at explosives-contaminated ranges. In Sunahara, G., J. Hawari, G. Lotufo, and R. Kuperman (eds.) Ecotoxicology of Explosives and Unexploded Ordnance, CRC Press, Boca Raton, FL.

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Theobald, D.M., T. Spies, J. Kline, B. Maxwell , N.T. Hobbs, V.H. Dale. 2005. Ecological support for rural land-use planning and policy. *Ecological Applications* 15(6): 1906-1914.

In review:

Dale, V.H., F. Akhtar, M. Aldridge, L. Baskaran, M. Berry, M. Browne, M. Chang, R. Efroymson, C. Garten, E. Lingerfelt, C. Stewart. Modeling impacts of land-use on quality of air, water, noise, and habitats for a five-county region in Georgia. *Ecology and Society*.

Report

Rizy, C.G., D.P. Vogt, and P. Beasley. Economic characterization of RSim counties. ORNL report.

Posters

Aldridge, M. GIScience 2004: Third International Conference on Geographic Information Science, October 20-23, 2004, University of Maryland.

Aldridge, M.L., M.W. Berry, W.W. Hargrove, F.M. Hoffman. Parallelization of a Hoshen-Kopelman Adaptation Using Finite State Machines. Supercomputing 2006. Tampa, Florida, Nov. 11-17, 2006.

Baskaran, L., V. Dale, M. Aldridge, M. Berry, M. Chang, R. Efroymson, C. Garten, and C. Stewart. RSim: A Regional Simulation to Explore Impacts of Resource Use and Constraints, Ecological Society of America annual meeting, Portland, OR, August 2004.

Baskaran, L., V. Dale, M. Aldridge, M. Berry, M. Chang, R. Efroymson, C. Garten, C. Stewart. 2004. RSim: A Regional Simulation to Explore Impacts of Resource Use and Constraints. Georgia URISA GIS/IT Conference at Peachtree City, GA, September 19 to 24, 2004.

Dale,V.H, M. Aldridge, L. Baskaran, M. Berry, M. Chang, R. Efroymson, C. Garten, L. Olsen, and R. Washington-Allen. RSim: A Regional Simulation to Explore Impacts of Resource Use and Constraints. SERDP Symposium, Washington ,D.C., December 2003.

Dale, V.H.,M. Aldridge, L. Baskaran, M. Berry, M. Chang, D. Druckenbrod, R. Efroymson, C. Garten, and R. Washington-Allen. Simulating Effects of Roads at Different Scales. SERDP Symposium, Washington, D.C., December 2004.

Dale, V.H., L. Baskaran, M.E. Chang, R. Efroymson, C. Garten, L. Olsen, M.W. Berry, M. Aldridge, and C. Stewart. Regional Simulation (RSim): Designing a tool to interface impacts of land-use change on air, water, noise, and habitat quality, Conference on Ecological Research in Tennessee. Cookeville, TN, February 2005.

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Washington-Allen, R., C. T. Garten, W. W. Hargove, T. L. Ashwood, and V. H. Dale. Regional Estimation of Nitrogen Loss in Relation to Military, Urban and Industrial Land Use Activities. Ecological Society of America annual meeting, Portland, OR August 2004.

Presentations

Baskaran, L. GIS and Remote Sensing today and an example of a research application – RSim. Invited talk at the Plateau PC Users Group, Inc in Crossville, TN, October 1, 2004.

Baskaran, L. Applications of GIS and Remote Sensing: The Regional Simulation Model (RSim) case study. Presentation at the Plateau PC Users Group, Inc in Crossville, TN, October 18, 2004.

Baskaran, L., V. Dale, M. and William Birkhead. Habitat modeling within a Regional Simulation Model (RSim) environment, Fourth Southern Forestry and Natural Resource Management GIS Conference, Athens, GA, December 16-17, 2004.

Chang, M., V. H. Dale, T. Ashwood, L. Baskaran, R. Efroymson, C. Garten, L. Olsen, M. W. Berry, M. Aldridge, and C. Stewart. The challenges in building RSim, a comprehensive resource management model, Presentation at conference on "Emerging Issues Along Urban/Rural Interfaces: Linking Science and Society," Atlanta, Georgia, March 13-16, 2005

Dale, V.H. Ecological Society of America Symposium on Land Use Change, Tucson, AR, August 2002

Dale, V.H. Pardee Symposium at the Geological Society of America, October 27, 2002 in Denver, CO

Dale, V.H. Meeting in Columbus, GA on research in the Fort Benning region, Columbus, GA, October 30, 2002

Dale, V.H. Botany Department, University of Tennessee, Knoxville, TN, November 2002

Dale, V.H. University of Washington, Seattle, WA, March 2003

Dale, V.H. University of Michigan, Ann Arbor, MI, March 2003

Dale, V.H. Keynote presentation for The American Society of Testing and Materials (ASTM International) Biological Effects and Environmental Fate Committee symposium on *Landscape Ecology and Wildlife Habitat Evaluation of Critical information for Ecological Risk Assessment, Land-use Management Activities, and Biodiversity Enhancement Practices.* April 7-9, 2003, Kansas City, KS.

Dale, V.H. Plenary lecture for 34th conference of the Ecological Society of Germany, Austria and Switzerland (GfÖ), Giessen, Germany, September 13-17, 2004

Dale, V.H. School of Agriculture, University of Tennessee, Knoxville, TN, February 2004

Dale, V. Keynote for Fourth Southern Forestry and Natural Resource Management GIS Conference, Athens, GA, December 16-17, 2004

Dale, VH. Plenary speaker for first meeting of the Brazilian Chapter of the International Association for Landscape Ecology, Caxambu, Brazil, November 21, 2005.

Dale, V.H. et al. “Modeling impacts of land-use on quality of air, water, noise, and habitats for a five county region in Georgia” Symposium at Annual meeting of the US Chapter of the International Association for Landscape Ecology, San Diego, CA, March 2006.

Druckenbrod, D. American Society of Agronomy Symposium, Denver, CO, October 2003.

Efroymson, R., V.H. Dale, M. Aldridge, M.W. Berry, C.T. Garten Jr, L.M. Baskaran, M. Chang and R.A.Washington-Allen. Transboundary ecological risk assessment at a military installation using the RSim model. United States Chapter of the International Association for Landscape Ecology. Special session on “Landscape ecological modeling and ecological risk assessment: at the cross roads.” Las Vegas, NE, April 1, 2004.

Efroymson, R.A. March 2005. Ecological risk assessment at Oak Ridge National Laboratory. Presentation to students in the Department of Energy's Student Undergraduate Laboratory Internships Program. Oak Ridge National Laboratory, Oak Ridge, TN.